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SAGEGRASS: A Sagebrush--Grass Grazingland Ecosystem Simulation Model

--Final Report to the BLM, 1981--

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by

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ABSTRACT

This report summarizes the major features of logic, assumptions, structure, and functioning of an ecosystem simulation model affectionately called "SAGE" (Sagebrush And Grass Ecosystem). The SAGE simulation model addresses a generalized sagebrush--grass grazingland ecosystem type typical of those in the western U.S.A. Work to date on this model has concentrated on two main problem areas--ecosystem conceptualization and computer coding of the model. Parameterization and testing of the model has begun.

The report describes the ecosystem which is modelled, the conceptual framework for the model, specific functional relationships used in the submodels, and technical aspects of the simulation methodology. The ecosystem was conceptualized using the state-variable approach. Inclusivity was brought into the model formulation so that flexibility was maintained. Three basic submodels were chosen for simulation: abiotic, plant, and animal. The level of resolution of the model was chosen so that multiple units of land could be simulated for periods of several to many years.

System function was methodically defined by developing a master list of variables and flows, structuring a generalized system flow diagram, constructing a flow-effects matrix, and conceptualizing interactive spatial units through spatial matrices. The process of developing individual mathematical functions representing the flow of matter and energy through the various system variables in different submodels is discussed.

The system model diagram identifies 9 subsystems which separately account for flow of soil temperatures, soil water, herbaceous plant biomass, shrubby plant biomass, tree cover, litter biomass, shrub numbers, animal biomass, and animal numbers.

A nomenclature system is developed for the driving variables, state variables, flows, intermediate variables, and parameters in the model. These terms are characterized in a standard algebraic notation and in PASCAL computer code, and are defined by reference and measurement units. The flow-effects matrix illustrates for each individual flow the various factors which are used in the calculation. The individual flow equations for the model are then specified algebraically and discussed in the text.

The model, coded in the computer language PASCAL, now operates on a CDC CYBER 172 computer. The model is generalizeable and canonical so that it can be expanded, if required, by disaggregating some of the system state variables and allowing for multiple ecological response units. This model, in effect, integrates information on climate, ecology, and management.

The overall model output is illustrated with time-series graphs and with tabular summaries for the mean, maximum and minimum value, time of maximum and minimum value, and standard deviation of driving variables, state variables, and flows.

DEDICATION

This report is dedicated to the memory of George M. Van Dyne whose untimely death just prior to the completion of this project left a large vacuum. We have finished this work with the hope that it would have met his high standards.

ACKNOWLEDGEMENTS

This report is the result of a combined effort by many members of the Systems Ecology Group, Range Science Department, Colorado State University. Some of the largest contributions were made by persons not mentioned on the title page. So, to these people, we extend our deepest thanks and acknowledge the high quality of their work.

Denese Dunkin,	who has helped oversee the development of this project from the start and keeps us mindful of deadlines.
Jane Love and Shelagh Cobb	who have painstakingly corrected countless revisions of the report and probably know it better than we do.
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Finally, we would like to thank the people at the BLM who have worked with us over the more than four years since the idea began, particularly Floyd Kinsinger, Alan Strobel, and Oscar Anderson.

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1. INTRODUCTION

The present paper is the final report on an ecological modelling activity. Work began on this project in fall 1978 with an initial review of literature of sagebrush--grass grazinglands in general and specifically summarizing simulation and optimization models. Both of these activities were reported (Van Dyne and Loehle 1979). The second progress report discussed initial modelling efforts in FORTRAN (Loehle and Van Dyne 1979). That early model was reworked in PASCAL and the abiotic section, previously taken from ELM (Cole 1976), was completely redone in a more efficient, consistent, and well documented manner. The third progress report presented an indexed bibliography on sagebrush--grass grazingland ecosystems containing information used in simulation model development (Loehle and Van Dyne 1979). The last progress report (Loehle, Jump, and Van Dyne 1980) summarized the status of model development.

This final report is self-contained and describes the modelling strategy, model structure and function, and implementation of the model on the Garat, a BLM allotment in SW Idaho.

1.1 Objectives

SAGEGRASS is a simulation model of the sagebrush--grass ecosystem. The objective of the model is to address the behavior of the ecosystem from the point of view of managers of large-scale grazing units. BLM personnel must manage large multiple-pasture allotments and districts. Because of low productivity, management is usually extensive rather than intensive. This extensive mangement nevertheless may completely alter the vegetation by the use of grazing, fire, fertilizer, or herbicides.

The above management activities are the type which SAGEGRASS is designed to simulate. Climatic variation, plant growth, animal grazing and reproduction, and management activities were factors to be addressed by SAGEGRASS. The model eventually must not only predict seasonal changes within a year but also changes occurring over any two decades.

All models are abstractions of reality. An abstraction such as a simulation model involves emphasizing certain aspects of ecosystem function, aggregating certain variables, and ignoring certain aspects of the ecosystem completely. Often this process proceeds based on the modeler's background or preference. In the case of the SAGE model, the degree of resolution, facets of the ecosystem emphasized, and management situations to be simulated were chosen to meet specific BLM--oriented objectives. The primary objective was to model the grazing situation, taking seasonal phenomena and species of grazing animal into account. When attempting to model an entire ecosystem, some constraint is needed on the modelling effort to prevent infinite complexity from being incorporated into the model. A goal was chosen of approximately 20% of the running time of ELM (Cole 1976), a very thorough and realistic grassland ecosystem model. The level of model complexity dictated by this execution time was felt to be the best trade-off between realism and a running time sufficiently low to allow the simulation of multiple pasture grazing systems.

In order to make the model usable, another necessary objective is to make the data needed to run the model reasonable. For example, the detailed data needed for initializing a soil nitrogen submodel is not generally available to the BLM. The data needs for the model are, thus, being manipulated so that all information needed should be available to BLM personnel. Thus, all information should be obtainable from the scientific literature, BLM or USGS maps, standard soil survey data, BLM vegetation inventories, and National Weather Service data files. Inputs of wildlife numbers may require estimated inputs from BLM staff.

1.2 Strategy

The model was structured using a state variable approach, although this was not strictly maintained at all times. The mathematical model consists of a series of linear and non-linear difference equations, plus logical relations. The system was structured according to abiotic, plant, and animal submodels, and is illustrated in the modified Forrester flow diagrams of Section 3.5.

The modelling strategy was to use PASCAL for the modelling language to implement a flow-oriented nonlinear difference equation simulation model. The PASCAL program includes the abiotic, plant, and animal components of the ecosystem. An extensive data structure was developed for handling data and managing program variables. Special discrete time events were implemented to mimic management activities.

Parsimony was applied at all stages of the top-down approach used to define the system. For the plant and animal components of the system, ecological theories about niches, life strategies, food webs, and trophic levels were used to guide the modelling process.

2. SAGEBRUSH--GRASSLAND SIMULATION

2.1 Ecosystem Description

The following section describes a general sagebrush--grass grazingland ecosystem and the general approach used in modelling it. The specific ecosystem serving as a test case for the model is described in Section 5.

2.1.1 Flora

Sagebrush is a component of many ecosystems in the western United States. The ecosystem addressed by SAGEGRASS is the Artemesia tridentata--Agropyron spicatum type. Other dominant plant species include Agropyron smithii, Chrysothamnus viscidiflorus, and Bromus tectorum. The area is generally dominated by open bunchgrass (or annuals on degraded range) with scattered to dense shrubs. Rainfall is generally low and sporadic, both seasonally and yearly. Vegetation growth is correspondingly sporadic. The type is found on most soil types in the proper climatic zone except on saline soils. Sagebrush has increased historically due to overgrazing and fire suppression.

A detailed literature review of the sagebrush--grass ecosystem would be extremely long and redundant since general ecological studies and reviews exist in abundance (Brown 1971, Christensen and Welsh 1963, Nielsen and Hinckley 1975, Saver and Uresk 1976, Vass and Lang 1938). Many major studies have also been done on management activities in this and related ecotypes (Blaisdell 1949, Cook 1971, Cook 1967, Frischknecht and Harris 1968, Hedrick et al. 1966, Hedrick et al. 1964, Hyder and Sneva 1963, Robertson 1947).

2.1.2 Fauna

Major grazing species include cattle, sheep, pronghorn antelope, mule deer, feral horses and burros, and small mammals. Grasshoppers may be significant consumers of herbage and occasionally produce outbreak populations. Management practices for domestic stock include selection of grazing season, grazing intensity, animal distribution, and species of animal.

For the general treatment of animal ecology and energetics undertaken by this model, a detailed review of the fauna of the sagebrush--grass ecosystem is not necessary.

2.1.3 Climate

Most of the sagebrush zone has a dry continental climate with cold winters. Winter precipitation (mostly snow) is important for plant growth. Day to night temperature differences are large. A more detailed treatment is given in Section 5 for the test area.

2.1.4 Management

To be useful to a land management agency, a simulation model should be able to mimic important management activities. The activities which may be addressed by the model include fire, herbicide application, plowing and seeding, tree harvest, fertilization, hunting, introducing wildlife, and adding, removing, and moving livestock. These activities are set up as discrete time events, described in Section 4.4.

2.2 Conceptualization of the Ecosystem

In the following sections the general conceptual framework of the model is laid out.

2.2.1 General Conceptualization

Framework Formulation. Abstracting and averaging the qualities of an ecosystem provides a uniform set of environmental conditions. But the large number of species present in an ecosystem is largely due to the variation in conditions from place to place, plus some diversity due to chance establishment, or chance effects on differential survival (Grime 1979). When all soil types are averaged or a particular type is chosen for modelling, and one square meter is modelled, the whole of which has the same soil and same climate, competitive exclusion indicates that only those plant species can be modelled which are able to partition a resource other than soil types. Vertical stratification of species with various degrees of shade tolerance for example, is not difficult to model and allows coexistence of several species. Such stratification may come into play in the sagebrush system in very dense stands. Seasonal differences in phenology are frequently important also (Grime 1979), and allow resource partitioning. The number of species which actually coexist in this way will generally only be a small percentage of the total number of species.

It is of course possible to force many species into a model by using an approach such as a Lotka-Volterra type sytem of equations. It is not difficult to define coefficients giving stable competitive interactions. Such an approach, by its success in allowing a kind of representation of many species systems, distracts attention from the real problem of modelling the system mechanistically.

If the above analysis is correct, then the "average square meter" approach to terrestrial ecosystem modelling is unable to handle questions related to diversity and is of dubious validity if many species are modelled simultaneously. Yet, few papers can be found containing caveats about the number of species which may be modelled.

A number of approaches may resolve this problem. These include predicting the presence or behaviour of minor species based on simulations of dominants, developing spatial models, modelling only selected portions of the ecosystem, and modelling only the most important species or aggregating species together.

Modelling large numbers of microsites in a very detailed or mechanisic way is beyond current computer storage and computation limits. It seems likely, however, that computers will continue to get bigger and faster. Prospects for vast increases in speed that are useful for simulation work are good due to the development of systems such as the ETH multiprocessor which, in contrast to previous multiprocessors, can handle highly nonlinear ODE systems with discontinuities, using power-series expansions (the Lie method) (Halin et al. 1980). If costs come down enough, then models with many interacting spatial units may become feasible. If a model is built with small patches differing in soil and microclimate, major conceptual problems must be overcome regarding spatial interrelations. Seed dispersal between patches, animal movement, intertwining of roots and branches. etc., would require some very complex data structures and algorithms for successful simulation. Given the time and money, it is likely that a large number of species could be modelled in a mechanistic way.

When project objectives call for information about minor species, it may be possible to avoid modelling a large series of microsites. For example, if major trees and shrubs in the forest are already being modelled explicitly, field studies might be able to establish moss and lichen abundance as simple functions of tree trunk surface area and total shade. Then lichen abundance can be a dependent variable predicted from variables being simulated.

If it is necessary to obtain information about rare or minor species without necessarily modelling the entire system, it may be possible to accomplish this by modelling a portion of the ecosystem. For example, tree lichens are sensitive to air pollution and can serve as an early indicator of biotic impacts. If we wish to model lichens as an indicator and do not really care about the total lichen biomass over some region, we can model lichens as a separate subsystem. Tree trunks provide the substrata and are assumed fixed in numbers and character during the simulation. The lichen microclimate is simulated based on weather data and forest microclimate relationships to macroclimate. Lichen physiology is simulated. The model is then used to test various levels of air pollution dispersed geographically from various combinations of point sources using a grid of simulated lichen colonies. In this way a map of potential impacts is produced before factories are built.

For resource management purposes it is often sufficient to know the behavior of a few dominant species or species groups, such as grasses, forbs, and shrubs. If a few species make up the vast majority of the site production and biomass and their niche partitioning is such that they can be modelled as occurring on the "average square meter", then simulation model design can proceed. Otherwise some form of aggregation of species is required.

In contrast to taxonomy where species are grouped by race, species, genus, etc., there is, at present, no general hierarchical classification scheme based on the species niche, functional group, adaptive strategy, or any other conceptual framework. Even if such a scheme existed, however, different simulation models would emphasize different aspects of the system, requiring unique approaches to aggregation. Unfortunately there is also no general technique for aggregating species together even in a mechanical, statistical way. In the absence of a theoretical framework, there are too many physical and physiological attributes by which species may be grouped for there to be any unique result.

For some very simple representations of systems, well defined conditions exist under which aggregation is possible. For example, in populations in which age structure is important, if a stable age distribution exists, then the cohorts can be aggregated together into a total population with a single growth rate parameter. Certain classes of simple models exist in which two species may be aggregated together if their rate parameters are similar enough. Simple systems of linear differential equations are an example of this. Most models do not fall into the above classes. Cole and O'dell (1979) show that for a one trophic level system modelled with linear differential equations, errors due to different kinds of aggregation of species may be characterized. However, no conclusions could be drawn concerning aggregation in non-linear models.

It is possible, given a particular model, to define somewhat arbitrary statistical criteria for aggregation. This is done via a kind of sensitivity analysis. Monte Carlo simulations of a major species are performed with model parameters for each run being chosen at random from the statistical distributions which represent the 95% confidence intervals (say) associated with each parameter. Any information on parameter covariance should of course be used. These model runs provide an estimate of the overall confidence limits on model performance. If a second species has seasonal dynamics that fall sufficiently within the confidence bounds of the first, in some statistical sense, then its seems reasonable to aggregate the species. The drawback to this approach is that there is no guarantee that given an arbitrary model, it will be possible to disaggregate two species even if project objectives should require it.

Since there is no rigorous method for defining species groups except after one is given a model which may not be appropriate, another approach is required. The approach taken in this project was to define the minimum set of species groups which the model would be able to distinguish, and then design the model so as to meet this goal. These species groups (trees, shrubs, warm grasses, cool grasses, forbs, cool annual grasses) were defined based on ecological intuition and BLM usage. The design of the model to meet this goal was based on competition theory and the concept of life strategies.

Parsimony. The objectives of the project dictated that parsimony should be a major strategic consideration during the process of conceptualizing the system. Variables and processes were only allowed to enter the model formulation when they were absolutely essential for meeting project objectives. Thus, the climate variables used and the structure of the soil heat and soil water submodels were entirely dictated by the requirements of the plant and animal submodels. Similarly, processes were only defined to the degree of detail required by overall objectives. In this way, modelling a particular process could not become a goal of its own.

Top-Down Approach. The conceptualization of the system was accomplished using a top--down approach. First, objectives were defined. Next, general subsystems were included or excluded (plants in, nutrient cycling out, stream flow out, animal energetics in, etc.) based on these objectives. Next, specific species types of major importance were considered. This defined food webs and the nature of the competitive interactions to be incorporated. The above considerations defined the general state variables and flows which were sometimes modified as work proceeded. Finally, flow functional forms and parameter values were defined and improved during model development.

Once the model purpose, scope, general resolution, and major species groups are defined, another step should be included before box and arrow diagrams are begun. This step involves defining the adaptive atrategy of each major species or group. This defines the major abiotic and biotic interactions and the mechanisms which must be modelled to allow simulation within the framework of the project goals. This step is usually skipped or at least is not made explicit, but doing so can lead to a model formulation that is unable to handle important aspects of the ecology of the species. Thus, in this project, going directly to box and arrow diagrams caused us to overlook the importance of ephemeral leaves in some species of sagebrush. By the time this oversight was discovered, the model structure and coding were so far along that including this factor would have been very difficult. If, instead, we had begun with an analysis like that of Orians and Solbrig (1977) or Grimes (1979) this would not have occurred. This approach has been used with some success. Botkin (1977) describes a model based on the niche using a functional approach. He concludes that the method is both theoretically and practically useful.

2.2.1.1 Abiotic conceptualization

The structure of the abiotic portions of the model was dictated largely by the plant submodel. Layers within the soil profile were required to distinguish between plant species with different rooting depths. Sticking to the canonical approach dictated that soil heat and soil water layers should correspond. Plant roots are divided between these layers. Air temperatures, soil water potentials, and day length are the main factors affecting plants. Soil temperature influences litter decomposition rates and evaporation and, in an earlier version of the model, affected root respiration. All other abiotic variables are basically needed to affect soil water and soil temperature.

2.2.1.2 Plant conceptualization

Structuring the plant submodel began with a consideration of the life strategies of and competition between the dominant life form types of the sagebrush ecosystem. The three dominant life forms are aromatic shrubs, perennial grasses, and perennial forbs. On disturbed sites annuals (mainly cheatgrass) may be dominant. These four types may be classified with Grimes' system (Grimes 1979) as stress-tolerant competitive, stress tolerant competitive, species of mixed types, and ruderal, respectively.

The major features of these types for modelling purposes revolve around competition and responses to grazing and climate. Aromatic shrubs (sagebrush and a few others) are deep rooted, long lived, slow growing, drought tolerant, fire sensitive, evergreen, and unpalatable to most animals. Perennial grasses (bluebunch wheatgrass) are faster growing, fire tolerant, long lived, moderately deeply rooted, moderately palatable, drought resistant, and grow mainly in early summer. Perennial forbs are very diverse but at least on the Snake River Plains most of them are early spring species (Blaisdell 1958). They are not very competitive with grasses and shrubs, usually being a small percentage of the total biomass. They were modelled as being similar to grasses with cooler season parameters and a lower growth rate. Annuals are drought sensitive, rapid growers, prolific seed producers, and unpalatable.

Using niche theory, it is clear that these growth form types can coexist because of spatial and temporal separation of their growing seasons and water use strategies. Fire also plays a part by limiting the dominance of sagebrush. During the conceptualization process, these characteristics were taken into account when determining which processes were to play a major role.

This process breaks down, however, when it is necessary to model a large number of species. Many of the rare species are either ruderal or occur on special microsites. Plants on such microsites may still be in competition with adjacent average sites to some degree. Attempting to model many microsites, such as small patches of disturbed soil, becomes a very complex task and multiplies simulation times tremendously. This is a fundamental problem in ecological modelling and it has not yet been resolved. Thus, it should not be assumed that the model can realistically handle more than five species on a particular ERU.

A further aspect of competition has to do with shading. Taller plants are assumed to shade lower plants. Plants of the same height shade each other. This process is analagous to the competition coefficients in a Lotka-Volterra type system; symmetric for plants of the same height, nonsymmetric for plants of differing heights. Shading as a competition factor thus stands for, and slightly exaggerates, the competitive advantage of larger plants in general. Self shading was not considered due to the generally low density of leaves in desert ecosystems.

In order to account for the effects of grazing, carbohydrate reserves had to be modelled. This caused difficulties because of the dearth of relevant field studies for parameter estimation. Grazing of cured forage dictated that standing dead vegetation had to be modelled as well.

The fact that no major grazing species eats significant amounts of pinyon or juniper meant that these species could be modelled as cover with simple logistic functions, thus saving on computer time.

2.2.1.3 Animal conceptualization

Parsimony was applied during the modelling of animal species. A detailed digestion model, for example, was not undertaken. The minimum number of cohorts was used for all species.

Niche theory indicates that some separation in resource use must occur. With only a few species of plants that can be modelled, it is not possible to model large numbers of distinct animal species. Many species can be put in the model but actually their parameters will be so similar that they are really just a few species, broken up into sub-populations and given different names.

The animal submodel consists of biomass and number currencies for several animal species. Age and sex cohorts are modelled for species needing this degree of resolution. The biomass currency is expressed as dry weight per individual, while the number currency is in terms of individuals per hectare.

3. SAGEGRASS MODEL STRUCTURE

3.1 System State Variables

The ecosystem is modeled using a state variable approach which entails the representation of parts of the ecosystem by discrete measurable quantities such as biomass or energy. This approach contrasts with partial differential equation models in which quantities are distributed in space, with models of the topology of the multi-population phase space, with set-theoretic models, and with other conceptual frameworks.

The state variable approach was chosen because it allows close representation of the logical relations between components of the ecosystem. Also, the difference equation representation describes the system in terms familiar to the range scientist such as photosynthesis per day, rainfall per day, etc.

3.2 System Processes

The complement of the state variables in this approach is the transfer process by which quantities are moved between state variables. All changes of state variables are accomplished via these transfers, referred to as processes, rates, or flows, and measured as units of quantity per unit of time. The standard time unit in this model is one day. While quantities within the model are not conservative, the sum of inputs to the model equals the sum of losses plus changes within the system.

The types of flows considered depend upon the objectives of the model. The detail with which a particular process is considered depends upon data availability, objectives, and an understanding of the process. All of these factors may change (and have) during the model development.

For discussing the mathematical form of the process functions a simplified notation is used: Z_i for a driving variable; F_i for a flow; X_i for a state variable; P_i for a parameter; I_i for intermediate variables. A full description is provided in Table 3.2. Model equations are discussed in Section 4.

3.3 Estimation of Parameters

Values for parameters must be specified in the model, and these must be based on the best estimates available. In some cases, sufficient experimental work has been accomplished or field measurements completed so that parameters are well documented. Model operation is dependent upon values specified for the parameters, and the model makes no distinction between those that are well documented and those that are based on estimated relationships. For parameters, without enough data for estimation, model runs were conducted and parameter values were varied until sufficiently realistic output was obtained.

The parameters in the present model are deterministic rather than stochastic. That is, for any given simulation run there are no random variations in parameter values.

Table 3.1. A process-effects matrix showing the items (time, driving variables, or state variables) that are used in calculating each flow in the different subsystems.

	DRIVING VARIABLES		SYSTEM STATE VARIABLES								
	CLIMATIC DRIVING VARIABLES	MANAGEMENT DRIVING VARIABLES	HEAT	WATER	HERB BIOMASS	SHRUB BIOMASS			SHRUB NUMBERS	ANIMAL BIOMASS	ANIMAL BIOMASS
	TIME TEMPERATURE, MAX TEMPERATURE, MIN RELATIVE HUMIDITY PRECIPITATION SOLAR ENERGY INPUT WIND VELOCITIES	HERD MANAGEMENT OVERSTORY STOCKING HUNTING SEASONS CONTROLLED BURN HERBICIDE APPLICATION RESEEDING (REVEGETATION) FERTILIZATION TREE CUTTING	TEMPERATURE, DEPTH J	SNOW RETAINED CHANNEL WATER VOLUME, DEPTH J GROUNDWATER	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	TREE COVER	LITTER	SHRUBS, CLASS Q	COHORT (N,0) DEAD ANIMALS	COHORT (N,0) DEAD ANIMALS
Heat Flow Submodel											
1. Shortwave radiation.	X			X	X X	X X	X	X	X		
2. Longwave radiation.	X		X								
3. Vaporization loss from soil depth 1.	X X X X		X	X X	X X	X X	X	X	X		
4. Reradiation from soil depth 1.	X X	X	X								
5. Net conduction between layers J and J+1.		X									
Water Flow Submodel											
1. Rainfall.	X X X										
2. Interception.	X X X			X	X X	X X	X	X	X		
3. Snowfall.	X X X			X							
4. Snow melt to retention.	X X			X							
5. Runoff.	X		X	X X X	X X		X	X	X		
6. Infiltration soil depth 1.	X X			X	X X	X X	X	X	X		
7. Evaporation from soil depth 1.	X X X X			X			X	X	X		
8. Net precolation between layers J and J+1.				X							
9. Transpiration from soil depth J.	X X X			X	X	X	X		X		
10. Drainage - in.				X							
11. Drainage - out.				X X							
12. Groundwater flow from source.				X							
13. Groundwater flow to sink.				X							
Herbage Biomass Flow											
1. Photosynthetic input.	X X	X		X	X	X	X		X		
2. Translocation to root depth J.	X X X			X	X X X						
3. Translocation to live shoots.	X X X			X	X X X						
4. Respiration from storage.	X X			X	X						
5. Respiration from root depth J.			X	X	X						
6. Respiration from live shoots.	X X			X							
7. Death from storage.	X X X	X		X	X						
8. Shoot death.	X	X		X							
9. Death of root depth J.	X X X	X		X	X						
10. Standing dead shattering.	X										
11. Fire loss, live shoots.	X	X			X					X	X
12. Fire loss, standing dead.	X	X			X					X	X
13. Shoot grazing.											
14. Dead grazing.											

Table 3.1. (Continued)

	DRIVING VARIABLES		SYSTEM STATE VARIABLES							
	CLIMATIC DRIVING VARIABLES	MANAGEMENT DRIVING VARIABLES	HEAT	WATER	HERB BIOMASS	SHRUB BIOMASS			SHRUB NUMBERS	ANIMAL BIOMASS	ANIMAL BIOMASS
	TIME TEMPERATURE, MAX TEMPERATURE, MIN PRECIPITATION RELATIVE HUMIDITY SOLAR ENERGY INPUT WIND VELOCITIES	HERD MOVEMENT DESTOCKING STOCKING HUNTING SEASONS CONTROLLED BURN HERBICIDE APPLICATION RESEEDING (REVEGETATION) FERTILIZATION TREE CUTTING	TEMPERATURE, DEPTH J	SNOW RETAINED CHANNEL WATER VOLUME, DEPTH J GROUNDWATER	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	TREE COVER	LITTER	SHRUBS, CLASS Q	COHORT (N,O) DEAD ANIMALS	COHORT (N,O) DEAD ANIMALS
Shrub Biomass Flow											
1. Photosynthesis.	X X	X		X X	X X	X X	X		X		
2. Translocation to root depth J.	X X X			X		X X X			X		
3. Translocation to green shoots.	X X X			X		X X X			X		
4. Translocation to woody material.						X X X			X		
5. Storage respiration.	X X			X							
6. Respiration from root depth J.			X	X		X			X		
7. Respiration from green shoots.	X X			X		X			X		
8. Respiration from woody material.	X X	X		X		X			X		
9. Storage death.	X X X	X		X					X		
10. Death of green shoots.	X X X	X				X			X		
11. Death of woody material.	X	X				X			X		
12. Death of root depth J.	X X X			X		X			X		
13. Fire loss, green shoots.	X	X				X			X		
14. Fire loss, woody material.	X	X				X			X		
15. Green shoot grazing.						X				X	X
16. Woody material grazing.						X				X	X
Tree Cover Flow											
1. Tree growth.	X						X				
2. Tree loss.	X						X				
3. Harvest.	X										
4. Fire loss.	X	X									
Litter Biomass Flow											
1. Input, herb shattering.	X				X X						
2. Input, shrub shattering.	X					X X			X		
3. Input, tree needle and twigs.	X						X			X	X
4. Input, fecal material.										X	X
5. Input, dead animals.	X										
6. Decomposition.			X	X				X			
7. Fire loss.	X		X								
8. Litter grazing.		X								X	X
Shrub Numbers Flow											
1. Recruitment fo small shrubs.	X X					X	X		X		
2. Maturation of small shrubs.				X	X	X X X X			X		
3. Mortality of shrubs, class Q.	X	X									
4. Fire loss of shrubs, class Q.	X	X									
Animal Biomass Flow											
1. Consumption by cohort (N,O).	X X X			X	X X	X			X	X	X
2. Natality of cohort (N,O).	X				X X	X X	X		X	X	X
3. Immigration/emigration of cohort (N,O).	X X X	X X		X	X X	X X			X	X	
4. Respiration of cohort (N,O).	X X			X	X X	X			X	X	
5. Mortality o cohort (N,O).	X X X	X			X X	X X	X		X	X X	
6. Dead animals to sink.										X	
Animal Numbers Flow											
1. Natality of cohort (N,O).	X									X	
2. Immigration/emigration of cohort (N,O).	X X X	X X		X	X X	X X			X		
3. Maturation, cohort (N,O) to cohort (N+1,O).	X									X	
4. Mortality of cohort (N,O).	X	X			X X	X X			X	X	X
5. Dead animals to sink.											X

3.4 Ecological Response Units

Selection of spatial units of reasonable size requires a compromise between too much and not enough detail. An ecological response unit is a composite spatial unit of combined physiognomic, climatic, soil, vegetative and animal features which make that type of area a noticeably unique system in terms of its response to varying conditions.

It is important to note that there is no foolproof technique for delineating vegetation types. Some schools of thought base vegetation types on dominant species, while others are based on species lists. Even statistical methods, such as principal components analysis and cluster analysis, may yield different communities depending on data quality and the objectives of the investigator. However, the level of resolution in this study dictates general community types such as sagebrush-grassland and pinyon-juniper forest which are distinct enough that no statistical delineation of types is needed. Similarly, there is no objective criteria currently available for lumping plant or animal species into functional groups.

Definition of a system of ecological response units must take into consideration the future of the region and the potential of the units for adapting to change resulting from natural resource management. The study units are designed so that they will be as meaningful 20 years from now as they are today. It is important, therefore, to evaluate a potential study unit in terms of its highly dynamic components compared to its minimally dynamic or static components. For example, in the absence of a natural catastrophe, it is probable that the elevation, slope, and aspect of a unit will not change over 20 years. Soil characteristics will change very slowly over time, while plant growth is highly dynamic.

Ecological response units should be defined such that they do not cross natural or manmade barriers which livestock are unable to cross. More than one ecological response unit (ERU) may be defined within a pasture.

3.4.1 Abiotic Components

Variables such as precipitation, air temperature, wind, and solar radiation influence all the ecological response units, yet these climatic variables remain sufficiently independent of interactions within those units and are therefore considered driving variables.

Abiotic variables such as soil temperature and soil water levels are considered system state variables. These variables are not independent from interactions and are characteristic components of the system. Additional resolution of some of these state variables is required. Thus, because the soil is divided into layers, heat flow between layers is needed.

3.4.2 Floral Components

Several hundred plant species occur in the major vegetation zones. This results in too many floral units for consideration in either a conceptual or numerical treatment. As a first step, the plants are grouped according to growth forms such as trees, shrubs, annual grasses, perennial forbs, and cool-season and warm-season perennial graminoids. Even so, considering the limited information available, further aggregation may be desirable.

The plant groups are then subdivided into structural compartments. Thus, within herbaceous plants, a live green component, a storage component, roots in each soil layer, and a standing dead component are identified. For shrubs there is a woody component but no standing dead.

3.4.3 Faunal Components

Animal species are grouped as mammals, birds, arthropods, reptiles and amphibians, and fish. As a second step, they may be disaggregated into sub-groups such as small mammals, medium-sized mammals, and large mammals, and for birds, into groups of omnivores, insectivores, and carnivores. Within each of these major groups of animals there are various species which are considered representative of the group. Again, information availability and model complexity do not allow inclusion of more than a small percent of the total number of animal species on an ERU.

Within any given animal category, changes in number and weight of the organisms are considered. Male and female organisms are considered separately and are grouped into three age classes: juvenile, immature, and mature.

3.5 System Flow Diagrams

The general flow diagrams, Figures 3.1-3.3, illustrates the compartmental structure of flows connecting state variables. There are essentially 10 currencies flowing in this system model. Nine of these currencies have a source and a sink so that the currency may enter and leave the system. Factors affecting flow controls are omitted for simplification but are discussed later with respect to the individual processes. The currencies flowing in the system model include degrees centigrade (calories converted to temperatures), meters (or volume) of water, grams per square meter of herbaceous plant biomass, grams per individual plant of shrub biomass, tree cover, grams per square meter of total plant and animal litter biomass, numbers of shrubs, kilograms per individual animal, and numbers of animals.

The flow diagrams illustrate the structures within a given terrestrial ecological response unit. Compartments are the boxes and source/sinks are ovals. Flows are labeled along the arrows. The third dimension depicted for some subsystems (herb biomass, shrub biomass, tree cover, shrub numbers, animal biomass, and animal numbers) refers to the different species or groups that might be included.

There is a correspondence in the belowground layers for soil temperature, soil water, and herb and shrub roots. The number and thickness of the layers

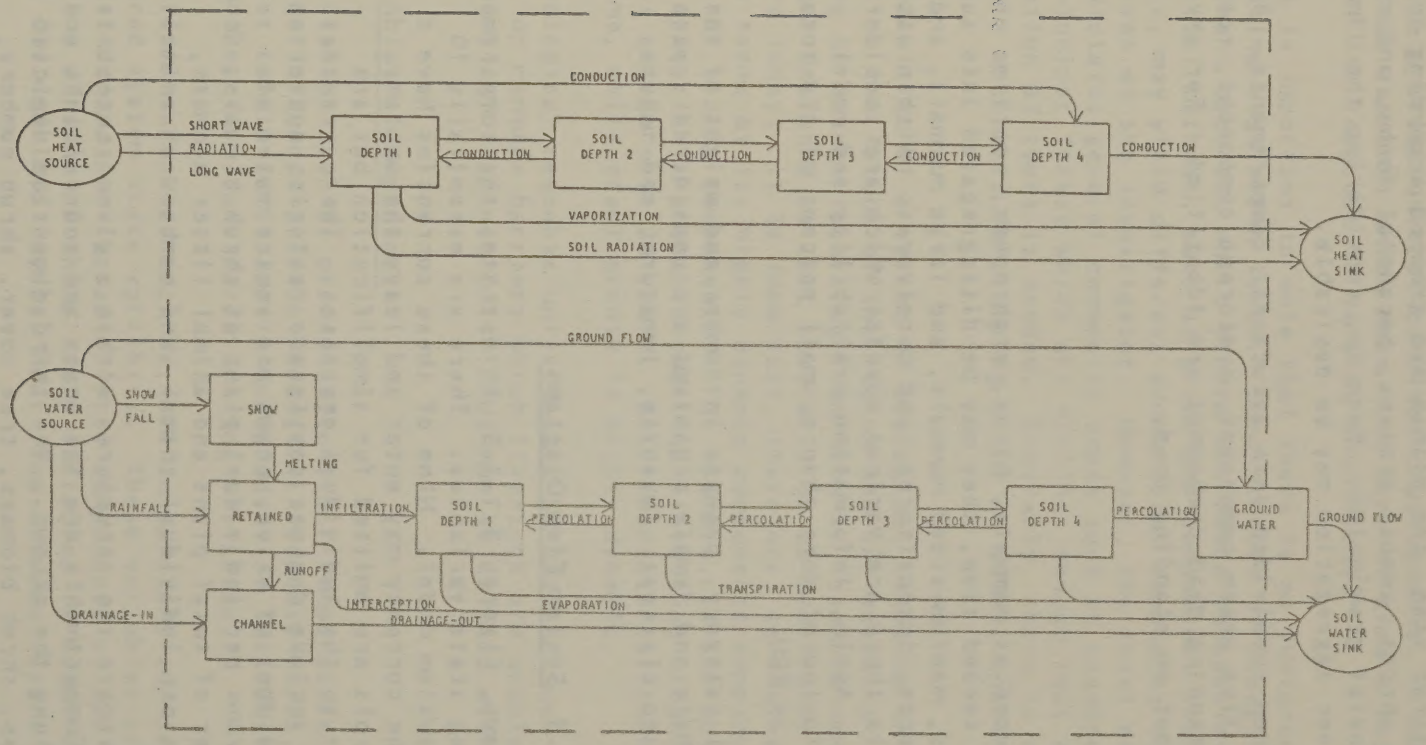


Figure 3.1. Forrester flow diagram for the soil heat and soil water submodels.

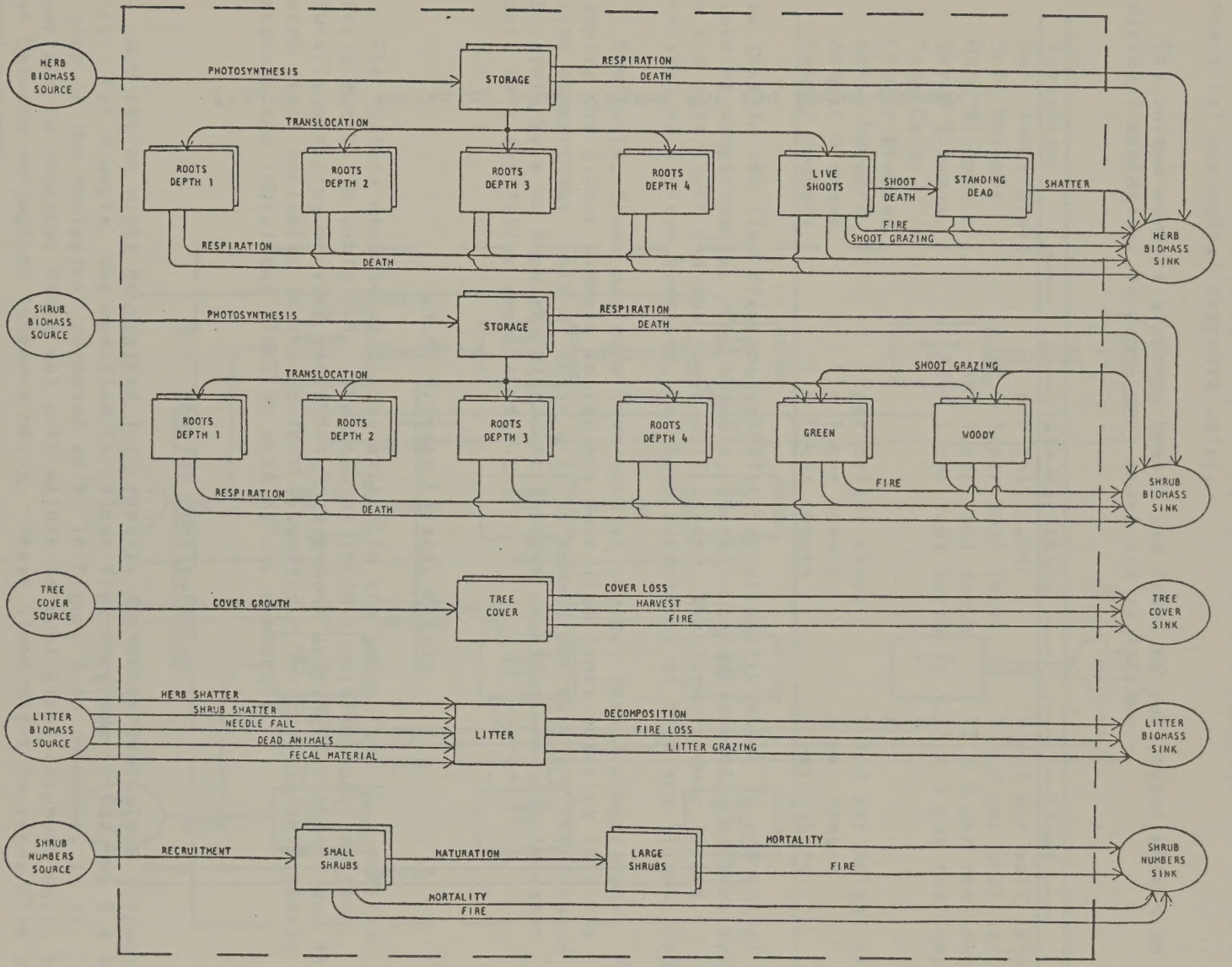


Figure 3.2. Forrester flow diagram for tree, litter, shrub, and herbaceous submodels.

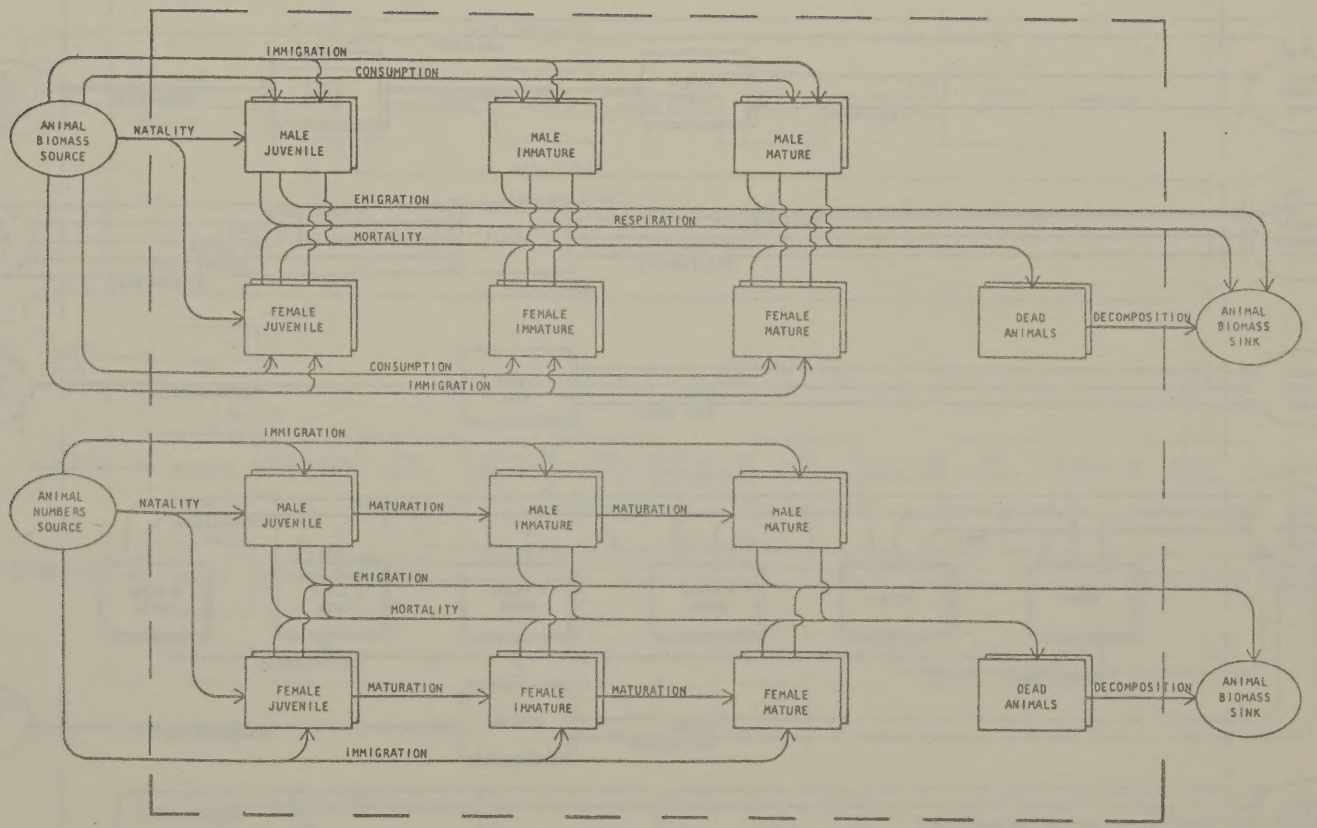


Figure 3.3. Forrester flow diagram for the fauna submodel.

can vary between ecological response units. Note that the surface must be thin, between 3 and 7 cm to allow realistic soil surface moisture and temperature for litter decay and seedling germination, and proper reradiation characteristics. The subsystems of Fig. 3.1–3.3 are repeated for different terrestrial ecological response units.

The unique numbers of compartments and flows by subsystems within an individual ecological response unit model are as follows:

Subsystem	State Variables	Flows
Soil Temperature	1 per soil layer	3 + 1 per soil layer
Soil Moisure	2 + 1 per soil layer	7 + 2 per soil layer
Herb Biomass	3 + 1 per root depth	12 + 3 per root depth
Shrub Biomass	3 + 1 per root depth	13 + 3 per root depth
Tree Cover	1	4
Litter Biomass	1	8
Shrub Numbers	1 per height class	2 + 2 per height class
Animal Biomass	1 + 1 per cohort	5 per cohort
Animal Numbers	1 + 1 per cohort	5 per cohort

Note that in the flow diagrams there are occasionally flows in and out of two adjoining compartments. For example, there is conduction flow of heat between the top soil layer and the lower soil layer. The flow is only in one direction at a given timestep, but both directions of flow are illustrated.

Similarly, flows may come from several sources into a compartment. For example, the litter biomass source has four flow lines entering into the litter compartment. All of these will be summed but they are represented separately here to show the different sources of plant and animal litter inputs into the litter compartment.

3.6 Process Effects Matrix

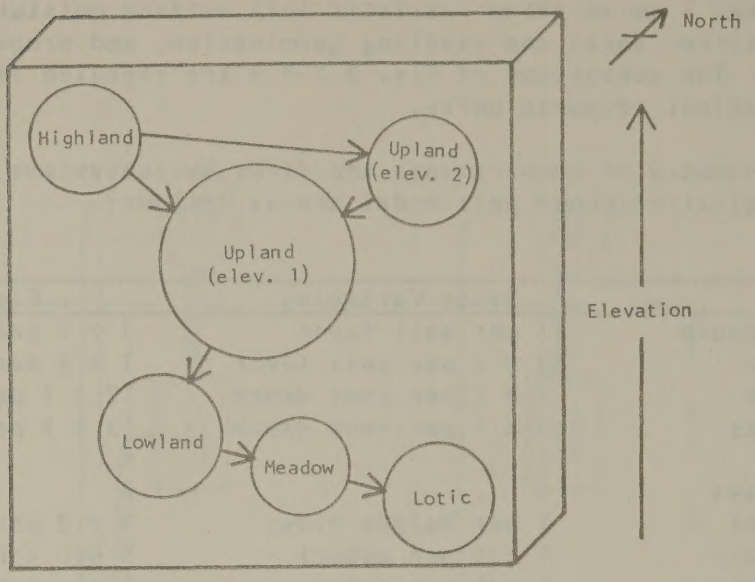
The factors used to calculate each flow are summarized in a process–effects matrix in Table 3.1. The columns in this matrix represent time, naturally occuring driving variables, management driving variables, and the system state variables in the various submodels. The rows in this matrix represent the individual flows in each of the submodels.

3.7 Spatial Configuration

Any region might be divided into several different ecological response units. For example, the modified Forrester flow diagrams in Section 3.4 apply to each of the ecological response units in Figure 3.4. However, it is important to consider flows not only within an ecological response unit, but also between ecological response units. These flows might be streamflow and animal movement.

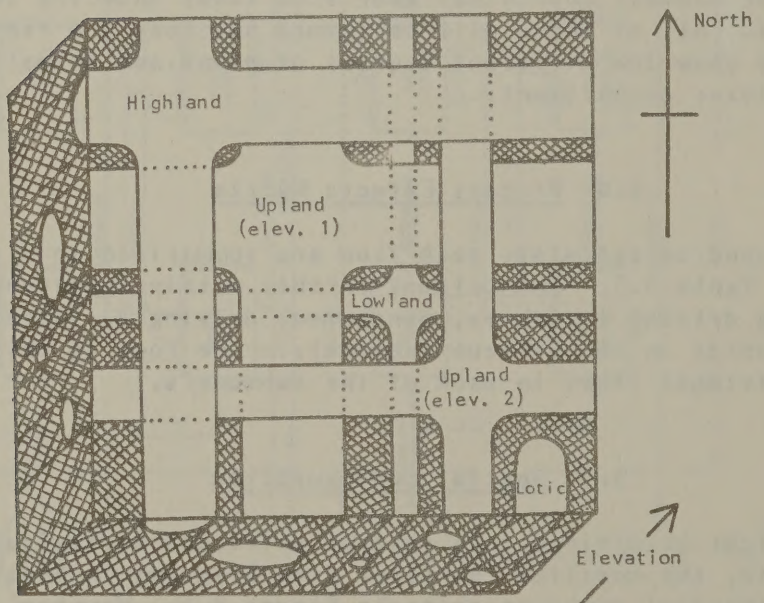
Consider, for example, the hypothetical piece of landscape shown in Figure 3.4. Six ecological response units are shown:

SIMPLIFIED INTRA-TOWNSHIP E.R.U. SPATIAL RELATIONSHIPS
(example shows the squatic flows)



A.

CONNECTION OF E.R.U.'s WITHIN A TOWNSHIP TO SIMILAR
E.R.U.'s WITHIN ADJACENT TOWNSHIPS



B.

Figure 3.4. Spatial relationships between E.R.U.'s. A. Example model structure for intra-township E.R.U. spatial connections for water flows. B. Connection of E.R.U.'s to similar E.R.U.'s in adjacent townships. See text for additional explanation.

(1) highland forested land;
(2) upland forested land;
(3) upland non-forested land;
(4) lowland shrub land;
(5) bottomland meadow;

Possible inter-township flows from one ecological response unit to another are shown in Fig. 3.5. For the same type of item flowing, e.g. water, deer or cattle, the quantity might be fixed in the case of water, but might be functions of the system condition in the case of deer or cattle. Currently animals can only move between townships as a result of a user-defined event.

Hydrology of the study area is not dealt with explicitly. The spatial structure for stream flow is incorporated into the model data structure so that stream flow could be added easily at a future date. Currently, when water runs off an ERU it is not kept track of. Thus, for implementing the model, stream channels do not need to be defined.

3.8 Temporal Description

Although change in any variable is continuous, time can also be aggregated. Thus, incremental changes rather than continuous changes of the above currencies (flows) or materials are considered. As a compromise between mechanistic detail and practicality, different time steps or increments can be used in calculating changes in content of soil heat, soil water, and plant and animal biomass and numbers within different components of an ecological response unit. The relations between the timesteps are defined by soil heat = soil water $\leq$ plant $\leq$ animal $\leq$ tree submodels. The minimum in all cases is one day. The maximum is one day for soil heat and soil water, one year for tree cover and the point at which output differs significantly from a one day timestep for the others, but in no case more than a month.

Consideration of the method for calculation of these changes leads to an initial attempt to express heat and water changes daily, plant biomass and numbers changes weekly, animal biomass changes weekly or bi-weekly, and tree cover on a yearly basis. Timesteps may be varied between simulation runs, longer timesteps giving shorter running times.

3.9 Nomenclature Master List

At this point it is useful to explicitly list the driving variables, system state variables, system intermediate variables and parameters. These are noted in Table 3.2. The variable names shown in Table 3.2 correspond with those in the text and computer code. The units and definition for each variable are indicated. Units should be carefully noted when setting up an input file for a run.

Table 3.2. A summary of terms used in the numerically implemented model. Terms include driving variables, state variables, flows, intermediate variables, and parameters. Terms are given both in a standardized notation for model descriptions and in the PASCAL code. The key to the standard notation follows:

Standard Notation	Interpretation
Z(t,#)	Driving variables t indicates the type of driving variables: C – climatic M – management
X(s,#)	State variables s indicates the associated submodel: 1 – soil temperature 2 – soil water 3 – herbaceous biomass 4 – shrub biomass 5 – tree basal area 6 – litter biomass 7 – shrub numbers 8 – animal biomass 9 – animal numbers 10 – land area
F(s,#)	Flow s indicates associated submodel
I(s,#)	Intermediate variables s indicates submodel which calculates it
P(s,#)	Parameter s indicates associated submodel
	In all cases, # indicates a sequential numbering system

Pascal Code Subscripts	Interpretation
I	day of year
J	soil depth-layer
K	soil class
L	plant class
M	fauna class
N	fauna age cohort
O	fauna sex cohort
P	season of year
Q	shrub size class
R	plant species
S	fauna species
T	time step
U	Ecological Response Unit
V	plant activity level

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
Z(C,1)	DATE	3.1.1	days	Julian date
Z(C,2)	TEMPMAX[I]	3.1.1	°C	Maximum air temperature of I-th day
Z(C,3)	TEMPMIN[I]	3.1.1	°C	Minimum air temperature of I-th day
Z(C,4)	TEMPMEAN[I]	3.1.1	°C	Mean air temperature of I-th day
Z(C,5)	WIND	3.1.1	km hr^{-1}	Total daily kilometers of wind
Z(C,6)	PRECIP	3.1.1	cm day^{-1}	Total daily precipitation
Z(C,7)	SHORTWAVE	3.1.1	ly day^{-1}	Shortwave radiation reaching the ground
Z(C,8)	DAYLIGHT	3.1.1	hr	Hours of daylight
Z(M,1)	INTENSITY	4.4.1	%	Fire intensity measured as percentage of vegetation burned
Z(M,2)	SPRAYSUCCESS	4.4.1	%	Percent kill of shurbs by herbicide
Z(M,3)	HUNT.SUCCESS	4.4.1	%	Hunter success as a percent of species population
Z(M,4)	HUNT.WOUND	4.4.1	%	Wounding loss as a percent of species population
Z(M,5)	STOCK.POPULATION	4.4.1	numbers	Number of animals stocked (or removed) from an ERU
Z(M,6)	FERTRATE	4.4.1	%	Percent increase in productivity due to fertilization Doubling of fertility would be 2.0
Z(M,7)	HARVESTPERCENT	4.4.1	%	Percent of tree species cover harvested

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
X(1,1)	LAYER[J].TEMP	4.2.1	°C	Temperature of J-th soil layer
X(2,1)	SNOW	4.2.2	cm	Depth of snow on surface of top soil layer
X(2,2)	RETAIN	4.2.2	m^3	Volume of water retained on surface of soil
X(2,3)	LAYER[J].MOIST	4.2.2	m^3	Volume of water in J-th soil layer
X(3,1)	BIOMASS.STORAGE	4.3.1.6	g m^{-2}	Storage biomass, herbaceous sp.
X(3,2)	BIOMASS.ROOT[J]	4.3.1.6	g m^{-2}	Root biomass in J-th soil layer, herbaceous sp.
X(3,3)	BIOMASS.GREEN	4.3.1.2	g m^{-2}	Green biomass, herbaceous sp.
X(3,4)	BIOMASS.NONGREEN	4.3.1.6	g m^{-2}	Standing dead biomass, herbaceous sp.
X(4,1)	BIOMASS.STORAGE	4.3.1.6	g (plant)$^{-1}$	Carbohydrate reserves, shrub sp.
X(4,2)	BIOMASS.ROOT[J]	4.3.1.6	g (plant)$^{-1}$	Roots in J-th soil layer, shrub sp.
X(4,3)	BIOMASS.GREEN	4.3.1.6	g (plant)$^{-1}$	Green biomass, shrub sp.
X(4,4)	BIOMASS.NONGREEN	4.3.1.2	g (plant)$^{-1}$	Woody aboveground biomass, shrub sp.
X(5,1)	TREECOVER	4.3.1.5	%	Tree cover
X(6,1)	LITTER.WEIGHT	4.3.2	g m^{-2}	Total litter biomass
X(7,1)	POPULATION	4.3.1.2	numbers m^{-2}	Number of shrubs of height class Q
X(8,1)	COHORT[N,O] .WEIGHT	4.3.3.1	g	Live biomass of N-th age and O-th sex cohort of a fauna species
X(8,2)	DEADWT	4.3.3.1	g	Dead biomass of a fauna species
X(9,1)	COHORT[N,O] .POPULATION	4.3.3.2	numbers	Individuals of N-th age and O-th sex cohort of a fauna species
X(9,2)	DEADIND	4.3.3.2	numbers	Dead individuals of a fauna species
X(10,1)	ACREAGE	4.2.4	ha	Undeveloped acreage within ERU
F(1,1)	RADIATE	4.2.1	cal cm^{-2} day^{-1}	Effective incoming shortwave radiation
F(1,2)	VAPORIZE	4.2.1	cal cm^{-2} day^{-1}	Heat loss due to evaporation from soil surface
F(1,3)	RERADIATE	4.2.1	cal cm^{-2} day^{-1}	Effective longwave radiation flux
F(1,4)	CONDUCT	4.2.1	cal cm^{-2} day^{-1}	Heat conduction flux between soil layers
F(2,1)	driving variable	4.2.2	m^3 day^{-1}	Total daily precipitation as rainfall
F(2,2)	INTERCEPTION	4.2.2	m^3 day^{-1}	Precipitation intercepted by plants
F(2,3)	input value	4.2.2	cm day^{-1}	Total daily precipitation as snowfall
F(2,4)	no specific term	4.2.2	m^3 day^{-1}	Snow melt water
F(2,5)	no specific term	4.2.2	m^3 day^{-1}	Runoff to channel
F(2,6)	INFILTRATE	4.2.2	m^3 day^{-1}	Water from surface into upper soil layer
F(2,7)	EVAPORATE	4.2.2	m^3 day^{-1}	Volume of water evaporated
F(2,8)	PERCOLATE	4.2.2	m^3 day^{-1}	Water flow between soil layers
F(2,9)	TRANSPIRE[J]	4.2.2	m^3 day^{-1}	Water taken up by plant roots from J-th soil layer
F(3,1)	NETPHOT	4.3.1.6	g m^{-2} day^{-1}	Flow of CO_2 to green biomass, herb. sp.
F(3,2)	ROOTTRANSL[J]	4.3.1.6	g m^{-2} day^{-1}	Flow from carbo. reserves to roots, J-th soil layer
F(3,3)	GREENTRANSL	4.3.1.6	g m^{-2} day^{-1}	Flow from carbo. reserves to green biomass, herb. sp.
F(3,4)	STORAGERESPIRE	4.3.1.6	g m^{-2} day^{-1}	Respiration from storage biomass, herb. sp.
F(3,5)	ROOTRESPIRE[J]	4.3.1.6	g m^{-2} day^{-1}	Respiration from roots, J-th soil layer
F(3,6)	GREENRESPIRE	4.3.1.6	g m^{-2} day^{-1}	Respiration from shoots, herb. sp.
F(3,7)	STORAGEDEATH	4.3.1.6	g m^{-2} day^{-1}	Loss from storage due to mortality, herb. sp.
F(3,8)	GREENDEATH	4.3.1.6	g m^{-2} day^{-1}	Flow from aboveground live to standing dead, herb. sp.
F(3,9)	ROOTDEATH[J]	4.3.1.6	g m^{-2} day^{-1}	Loss due to mortality from roots, J-th soil layer
F(3,10)	GREENBURN	4.3.1.6	g m^{-2} day^{-1}	Fire consumption of green biomass, herb. sp.

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
F(3,11)	GREENGRAZE	4.3.3.1	g m^{-2} day^{-1}	Grazing of green biomass, herb. sp.
F(3,12)	DEADSHATTER	--	g m^{-2} day^{-1}	Flow from standing dead to litter, herb. sp.
F(3,13)	DEADBURN	--	g m^{-2} day^{-1}	Fire consumption of standing dead biomass, herb. sp.
F(3,14)	DEADGRAZE	4.3.3.1	g m^{-2} day^{-1}	Grazing of standing dead biomass, herb. sp.
F(3,15)	LEAFFALL	4.3.1.6	g m^{-2} day^{-1}	Flow from green biomass to litter, herb. sp.
F(4,1)	NETPHOT	4.3.1.6	g m^{-2} day^{-1}	Flow from CO_2 to green biomass, shrub sp.
F(4,2)	ROOTTRANSL[J]	4.3.1.6	g $plant^{-1}$ day^{-1}	Flow from carbo. reserves to roots, J-th soil layer
F(4,3)	GREENTRANSL	4.3.1.6	g $plant^{-1}$ day^{-1}	Flow from carbo. reserves to green biomass, shrub sp.
F(4,4)	STORAGERESPIRE	4.3.1.6	g $plant^{-1}$ day^{-1}	Respiration from storage biomass, shrub sp.
F(4,5)	ROOTRESPIRE[J]	4.3.1.6	g $plant^{-1}$ day^{-1}	Respiration from roots, J-th soil layer
F(4,6)	GREENRESPIRE	4.3.1.6	g $plant^{-1}$ day^{-1}	Respiration from shoots, shrub sp.
F(4,7)	STORAGEDEATH	4.3.1.6	g $plant^{-1}$ day^{-1}	Loss from storage due to mortality, shrub sp.
F(4,8)	LEAFFALL	4.3.1.6	g $plant^{-1}$ day^{-1}	Flow from green biomass to litter, shrub sp.
F(4,9)	ROOTDEATH[J]	4.3.1.6	g $plant^{-1}$ day^{-1}	Loss due to mortality from roots, J-th soil layer, shrub sp.
F(4,10)	GREENBURN	--	g $plant^{-1}$ day^{-1}	Fire consumption of green biomass, shrub sp.
F(4,11)	GREENGRAZE	4.3.3.1	g $plant^{-1}$ day^{-1}	Grazing of green biomass, shrub sp.
F(4,12)	WOODYTRANSL	4.3.1.6	g $plant^{-1}$ day^{-1}	Flow from carbo. reserves to woody biomass, shrub sp.
F(4,13)	WOODYRESPIRE	4.3.1.6	g $plant^{-1}$ day^{-1}	Respiration from woody biomass, shrub sp.
F(4,14)	WOODYBURN	--	g $plant^{-1}$ day^{-1}	Fire consumption of woody biomass, shrub sp.
F(4,15)	WOODYGRAZE	4.3.3.1	g $plant^{-1}$ day^{-1}	Grazing of woody biomass, shrub sp.
F(4,16)	LITTERFALL	--	g $plant^{-1}$ day^{-1}	Flow from woody biomass to litter, shrub sp.
F(5,1)	TREEGROWTH	4.3.1.5	m^2 day^{-1}	Flow from source to tree cover, tree sp.
F(5,2)	TREELOSS	4.3.1.5	m^2 day^{-1}	Flow from cover to sink, tree sp.
F(5,3)	TREELOSS	4.3.1.5	m^2 day^{-1}	Rate of harvest of trees
F(5,4)	TREEBURN	4.3.1.5	m^2 day^{-1}	Rate of burning of trees
F(6,1)	no specific term	4.3.2	g m^{-2} day^{-1}	Tranfer to litter from herbs
F(6,2)	no specific term	4.3.2	g m^{-2} day^{-1}	Transfer to litter from shrubs
F(6,3)	no specific term	4.3.2	g m^{-2} day^{-1}	Transfer to litter from trees
F(6,4)	EXCRETION	4.3.2	g m^{-2} day^{-1}	Transfer to litter from animal feces
F(6,5)	CARCASS	4.3.2	g m^{-2} day^{-1}	Transfer to litter from dead animals
F(6,6)	DECOMPABOVE	4.3.2	g m^{-1} day^{-1}	Flow of litter to sink
F(6,7)	LITTERBURN	4.3.2	g m^{-2} day^{-1}	Consumption rate of litter by fire
F(6,8)	LITTERGRAZE	4.3.2	g m^{-2} day^{-1}	Grazing of litter by animals
F(7,1)	RECRUITMENT	4.3.1.7	numbers m^{-2} day^{-1}	Flow from sources to number small shrubs
F(7,2)	MATURATION	4.3.1.7	numbers m^{-2} day^{-1}	Flow from small shrub to large shrub numbers
F(7,3)	SHRUBDEATH	4.3.1.7	numbers m^{-2} day^{-1}	Natural mortality of shrubs of a height class
F(7,4)	SHRUBBURN	4.3.1.7	numbers m^{-2} day^{-1}	Fire caused mortality of shrubs of a height class
F(8,1)	ASSIMILATE	4.3.3.1	g day^{-1}	Consumption, assimilation and respiration by faunal species cohorts
F(8,2)	RECRUIT	4.3.3.2	g day^{-1}	Recruitment of male and female juveniles
F(8,3)	IMMIGRATE/ EMIGRATE	4.3.3.2	g day^{-1}	Immigration/emigration of faunal species cohorts
F(8,4)	BEDEAD	4.3.3.1	g day^{-1}	Mortality of faunal species cohorts
F(8,5)	DECOMPOSE	--	g day^{-1}	Decomposition of dead animals
F(9,1)	RECRUIT	4.3.3.2	numbers day^{-1}	Recruitment of male and female juveniles
F(9,2)	IMMIGRATE/ EMIGRATE	4.3.3.2	numbers day^{-1}	Immigration/emigration of faunal species cohorts
F(9,3)	AGING	4.3.3.2	numbers day^{-1}	Maturation of male and female cohorts
F(9,4)	BEDEAD	4.3.3.2	numbers day^{-1}	Mortality of faunal species cohorts
F(9,5)	DECOMPOSE	--	numbers day-1	Decomposition of dead animals

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
I(1,1)	C[J]	4.2.1	cal $(cm^3\ °C)^{-1}$	Volumetric heat capacity of J-th soil layer
I(1,2)	LAMDA[J]	4.2.1	cal $(cm\ sec\ °C)^{-1}$	Thermal conductivity of J- th soil layer
I(2,1)	THETA[J]	4.2.2	%	Volumetric water content of J-th soil layer
I(2,2)	LAYER[J] .POTENTIAL	4.2.2	bars	Difference in free energy per unit volume between matrically bound water and that of pure water of J-th soil layer
I(2,3)	H[J]	4.2.2	m	Hydraulic suction head of J-th soil layer
I(2,4)	K[J]	4.2.2	$m\ sec^{-1}$	Hydraulic conductivity of J-th soil layer
I(2,5)	KAVE[J]	4.2.2	$m\ sec^{-1}$	Average hydraulic conductives between the J-th and (J+1) soil layers
I(2,6)	WFACTOR[J]	4.2.2	no units	Weighting factor for metric potential of J-th soil layer
I(2,7)	WSUM	4.2.2	no units	Sum of weighting factors
I(2,8)	MAXRATE	4.2.2	cm	Maximum infiltration rate
I(2,9)	IS[L]	4.2.2	cm	Interception storage modified by amount of rainfall for L-th plant class
I(3,1)	LEAFAREA	4.3.1.2	$dm^2\ m^{-2}$	Leaf area index, top side of leaf
I(3,2)	MU	4.3.1.6	%	Maximum net photosynthesis rate as a function of soil water potential
I(3,3)	WATEREFFECT	4.3.1.6	%	Reduction in photosynthate allocation to roots and tops due to reduced soil water
I(3,4)	no specific term	4.3.1.6	%	Effect of soil water and temperature on net photosynthesis
I(3,5)	FERTIL	4.3.1.5	%	Site quality effect on photosynthesis
I(3,6)	TH	4.3.1.6	°C	Maximum temperature for net photosynthesis
I(3,7)	TOX	4.3.1.6	°C	Optimal temperature for net photosynthesis, affected by soil water
I(3,8)	TEMPEFFECT	4.3.1.6	%	Decrease in total translocation as temperature becomes less than optimal
I(3,9)	SHADE	4.3.1.6	$dm^2\ m^{-2}$	Amount of leaf area shading
I(3,10)	AVEPOTENTIAL[V]	4.3.1.6	bars	Soil water potential in the wettest zone containing roots for days in activity class V
I(3,11)	TRANS	4.3.1.6	g m^{-2} or g $plant^{-1}$	Total translocate
I(3,12)	STRUCTURE	4.3.1.6	g m^{-2} or g $plant^{-1}$	Total structural biomass of plant
I(3,13)	TOTAL.COVER	4.3.1.6	%	Total percent cover of vegetation, live + dead
I(3,14)	LIVECOVER	4.3.1.6	%	Percent of total live cover by species
I(3,15)	TOTCOVER	4.3.1.6	%	Percent of total cover by species
I(3,16)	ACTIVE	4.3.1.1	no units	Index value for activity class V
I(3,17)	INACTIVE	4.3.1.1	no units	Index value for activity class V
I(3,18)	PLANTDAYS[V]	4.3.1.1	days	Number of days in activity class V
I(3,19)	AVEMAXT[V]	4.3.1.1	°C	Average maximum temperature for days in activity class V
I(3,20)	AVEMINT[V]	4.3.1.1	°C	Average minimum temperature for days in activity class V
I(3,21)	AVETEMP[V]	4.3.1.1	°C	Average daily mean temperature for days in activity class V
I(3,23)	DROUGHTDAYS	4.3.1.1	days	Number of days during which available soil water is below the wilting point
I(3,24)	DROUGHTSTRESS	4.3.1.1	bars	Average water potential for days below the wilting point
I(3,25)	ROOTDAYS[J][V]	4.3.1.1	days	Number of days during which soil layer J is above the wilting point and above freezing
I(3,26)	ROOTWATER[J]	4.3.1.6	bars	Soil water potential in the J-th layer averaged for days above the wilting point
I(3,27)	ROOTTEMP[J]	4.3.1.6	°C	Soil temperature in the J-th layer averaged for days above the wilting point
I(3,28)	TOTAL.LIVECOVER	4.3.1.6	%	Total live cover

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
I(4,1)	WATERRECRUIT	4.3.1.7	%	Effect of surface soil moisture on small shrub invasion
I(4,2)	TCOMP	4.3.1.7	%	Effect of competition on small shrub invasion
I(4,3)	TEMPRECRUIT	4.3.1.7	%	Effect of surface temperature on shrub germination
I(5,1)	MAXCOVER	4.3.1.5	%	Maximum tree cover that can be attained on an ERU Input by user for each ERU.
I(8,1)	METABASE	4.3.3.1	cal g^{-1}	Calories needed for basal metabolism
I(8,2)	CONDUCTANCE	4.3.3.1	cal $°C^{-1}$	Rate at which an animal body gains or losses heat
I(8,3)	CRITICALTEMP	4.3.3.1	°C	Lower critical temperature of thermoneutrality
I(8,4)	METATHERM	4.3.3.1	cal g^{-1}	Calories needed for maintenance of thermal regulation
I(8,5)	MOVEMENT	4.3.3.1	km	Distance traveled during one time step
I(8,6)	VELOCITY	4.3.3.1	km hr^{-1}	Average velocity of movement
I(8,7)	METAMOVE	4.3.3.1	cal g^{-1}	Metabolic calories needed for activity
I(8,8)	METAGROW	4.3.3.1	cal g^{-1}	Calories needed for biomass production
I(8,9)	ENERGYBASE	4.3.3.1	cal	Calories needed for all metabolic needs other than growth
I(8,10)	ENERGYGROW	4.3.3.1	cal	Calories needed for all metabolic needs
I(8,11)	NEED	4.3.3.1	g	Biomass needed of a food species
I(8,12)	AVAILABLE	4.3.3.1	g	Biomass available of a food species
I(8,13)	ABUNDANCE	4.3.3.1	%	Relative abundance of a food species to its total demand
I(8,14)	RELSCARCITY	4.3.3.1	%	Relative scarcity of a food species to an individual consumer species
I(8,15)	ALLOT	4.3.3.1	g	Biomass of a food specie alloted to a consumer specie
I(8,16)	ENERGYFLUX	4.3.3.1	cal	Difference between the metabolic needs and the calories supplied through all foods consumed
I(9,1)	AGEOF	4.3.3.2	days	Age of a particular species cohort
I(9,2)	NATDEATH	4.3.3.2	numbers	Number of individuals dying of "natural" causes
I(9,3)	PREDATE	4.3.3.2	numbers	Number of individuals dying from predation
I(9,4)	HUNT	4.3.3.2	numbers	Number of individuals dying from legal hunting and wounding losses
I(9,5)	CONDITION	—	%	Index of animal condition
I(9,6)	HABVAR[SNOW]	4.3.3.2	no units	Habitat rating of an ERU's snow condition for a species
I(9,7)	HABVAR[TEMP]	4.3.3.2	no units	Habitat rating of an ERU's temperature condition for a species
I(9,8)	HABVAR[COVER]	4.3.3.2	no units	Habitat rating of an ERU's cover condition for a species
I(9,9)	HABVAR[FOOD]	4.3.3.2	no units	Habitat rating of an ERU's food condition for a species
I(9,10)	HABVAR[PREVPOP]	4.3.3.2	no units	Habitat rating of an ERU's population condition for a species
I(9,11)	HABVAR[COMBINED]	4.3.3.2	no units	Sum of an ERU's habitat condition ratings for a species
I(9,12)	TWNTOTAL	4.3.3.2	numbers	Total species population existing within a township
I(10,1)	LAYER[J].MIDDEPTH	4.2.4	m	Depth at midpoint of J-th soil layer
I(10,2)	FERTIL	4.3.3	no units	Current site fertility
I(C,1)	PEVAP	4.2.2	cm	Potential evaporation from a pan of water
I(C,2)	TEMPFACTOR	3.1.2	%	Percent adjustment to driving variable temperature based on elevation
I(C,3)	RAINFACTOR	3.1.2	%	Percent adjustment to driving variable rainfall based on elevation
I(C,4)	PTRANS	4.2.2	cm	Potential transpiration

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(1,1)	SPDEN[K]	4.2.1	g cm^{-2}	Specific density of K-th soil type
P(1,2)	SPHEAT[K]	4.2.1	cal $(g\ °C)^{-1}$	Specific heat of K-th soil type
P(1,3)	EARTHTEMP	4.2.1	°C	Temperature of earth below lowest layer
P(1,4)	EMISSIVITY	4.2.1	%	Relative ability of the earth to radiate energy
P(1,5)	ALBEDOPLANT	4.2.1	%	Average plant surface albedo
P(1,6)	LMINERAL	4.2.1	10^{-3} cal $(cm\ sec\ °C)^{-1}$	Thermal conductivity of mineral component of the soil
P(1,7)	LORGANIC	4.2.1	10^{-3} cal $(cm\ sec\ °C)^{-1}$	Thermal conductivity of organic matter component of the soil
P(1,8)	LWATER	4.2.1	10^{-3} cal $(cm\ sec\ °C)^{-1}$	Thermal conductivity of water component of the soil
P(1,10)	STEFBOLTZ	4.2.1	cal $(cm^2\ °C\ day)^{-1}$	Stefan Boltzman constant
P(1,11)	VAPORBASE	4.2.1	cal	Energy required for vaporization at 0°C
P(1,12)	VAPORGRAD	4.2.1	cal $°C^{-1}$	Energy gradient for vaporization per 0°C
P(1,13)	BASEKELVIN	4.2.1	°K	Converts °C to °K
P(1,14)	SPHTH20	4.2.1	cal $(g\ °C)^{-1}$	Specific heat of water
P(1,15)	SPDENH20	4.2.1	g cm^{-2}	Specific density of water
P(1,16)	SPHTHUMUS	4.2.1	cal $(g\ °C)^{-1}$	Specific heat of humus
P(1,17)	SPDENHUMUS	4.2.1	%	Specific density of humus
P(2,1)	SATK[K]	4.2.2	m sec^{-1}	Hydraulic conductivity at saturation of K-th soil type
P(2,2)	SATTHETA[K]	4.2.2	%	Volumetric water content at saturation of K-th soil type
P(2,3)	FIELDCAP[K]	4.2.2	%	Volumetric content of field capacity of K-th soil type
P(2,4)	BAR3THETA[K]	4.2.2	%	Volumetric water content at 3 bars water tension for K-th soil type
P(2,5)	WILTTHETA[K]	4.2.2	%	Volumetric water content at wilting point for K-th soil type
P(2,6)	COE[L]	4.2.2	%	Intercepted water evaporated from plant surface for L-th plant class
P(2,7)	ISC[L]	4.2.2	%	Intercepted water retained on plant surface for L-th plant class
P(2,8)	DEWTEMP	4.2.2	°C	Threshold evaporation temperature
P(2,9)	MELTRATE	4.2.2	cm $°C^{-1}$	Rate of snow melt
P(2,10)	MELTTEMP	4.2.2	°C	Threshold melting temperature
P(2,11)	STREAM.RATE	4.2.2	m^3 day^{-1}	Stream discharge rate
P(2,12)	SEEPRATE	4.2.2	%	Seepage rate from stream to deep soil layer
P(2,13)	SNOWMOIST	4.2.2	cm $(cm\ HOH)^{-1}$	Moisture content of snow
P(2,14)	SNOWTEMP	4.2.2	°C	Threshold snowfall temperature
P(3,1)	B	4.3.1.6	%	Parameter controlling relative allocation of photosynthate
P(3,2)	HPSIMORT	4.3.1.6	g m^{-2} bar^{-1} day^{-1}	Rate at which green biomass dies per unit of moisture potential below PSIMORT
P(3,3)	K3	4.3.1.6	no units	Shape parameter
P(3,4)	K4	4.3.1.6	no units	Parameter for rate of reduction of MU with water potential
P(3,5)	K5	4.3.1.6	no units	Parameter for rate of reduction of TH with water potential
P(3,6)	K6	4.3.1.6	no units	Parameter for rate of reduction of TOX with water potential
P(3,7)	KD	4.3.1.6	% day^{-1}	Protein degradation rate
P(3,8)	ROOTDEPTH	4.3.1.6	cm	Depth in cm of deepest penetration of roots by a specie
P(3,9)	PMAX	4.3.1.6	(g dry wt) dm^{-2} hr^{-1}	Maximum net photosynthetic rate in g dry weight
P(3,10)	PSIMORT	4.3.1.6	bars	Moisture potential causing plant mortality
P(3,11)	RX	4.3.1.6	g day^{-1}	Maximum translocation rate at high levels of stored energy
P(3,12)	GPRIORITY	4.3.1.6	%	Green biomass at which all translocation goes to green, as a percent of all structural biomass except green

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(3,13)	MINSTORAGE	4.3.1.6	g	Storage biomass at which plant die back begins as a percent of total biomass
P(3,14)	TL	4.3.1.6	°C	Minimum temperature for net photosynthesis
P(3,15)	TMAX	4.3.1.6	°C	Maximum temperature for net photosynthesis under nonlimiting soil water
P(3,16)	TOPT	4.3.1.6	°C	Optimal temperature for net photosynthesis under nonlimiting soil water
P(3,17)	XDEATH	4.3.1.6	%	Rate of death of green biomass per unit of temperature below threshold
P(3,18)	TRANSBELOW	4.3.1.6	%	Percent of total translocate which goes belowground
P(3,19)	EXPAND	4.3.1.6	bars	Soil water potential at which leaf expansion is inhibited
P(3,20)	RDEATH	4.3.1.6	%	Root death rate per unit of soil water potential below PSIMORT
P(3,21)	XSHADE	4.3.1.6	%	Percent reduction in net photosynthesis due to competing vegetation
P(3,22)	GTOLAI	4.3.1.2	$dm^2\ g^{-1}$	Conversion factor for leaf area per g of leaf biomass
P(3,23)	SHATTER	—	$g\ day^{-1}$	Nominal rate of transfer of standing dead to litter
P(3,24)	WILTPT	4.3.1.6	bars	Wilting point
P(3,25)	EFFICIENCY	4.3.1.6	%	Conversion efficiency of carbohydrates to structure
P(3,26)	FREEZE	4.3.1.6	°C	Temperature at which mortality of green biomass begins
P(3,27)	XPALL	4.3.1.6	°C	Temperature below which translocation is inhibited
P(3,28)	PROTEIN.LEAF[P]	4.3.1.6	%	Percent protein of leaves
P(3,29)	PROTEIN.ROOT[P]	4.3.1.6	%	Percent protein of roots
P(4,1)	ZRECRUIT	—	g	Average woody biomass above which recruitment begins to larger size class
P(4,2)	ZAI	4.3.1.7	$numbers\ m^{-2}\ day^{-1}$	Nominal shrub germination rate
P(4,3)	ZCA	4.3.1.7	dm^{-2}	Effect of shade on shrub invasion
P(4,4)	ZLEAFDEATH	—	%	Percent of leaves lost during leaf abscission
P(4,5)	ZLEAFFALL	—	julian date	Date at which leaves fall
P(4,6)	ZSTEMDEATH	—	%	Nominal stem death rate
P(4,7)	ZRECR	4.3.1.7	$\%\ day^{-1}$	Percent of small shrubs that move to large size class per day
P(4,8)	PROTEIN.WOODY[P]	4.3.1.6	%	Percent protein of wood minus nonstructural carbohydrates
P(5,1)	TREEGROW	4.3.1.5	$m^2\ day^{-1}$	Nominal growth rate for a tree species
P(5,2)	TREEGPERM2	—	$g\ m^{-2}$	Grams of leaf per m^2 of cover
P(5,3)	TREEGTOLAI	—	$dm^2\ g^{-1}$	Conversion factor for leaf area from units of leaf biomass
P(5,4)	TREEPK4	—	no units	Rate of reduction of transpiration with decreasing soil water potential
P(5,5)	TREEWILT	—	bars	Wilting point for trees
P(5,6)	TURNOVERRATE	4.3.1.5	%	Daily percentage of tree needles lost
P(6,1)	LWILT	4.3.2	bars	Analogous to wilting point for litter. Point at which decay stops
P(6,2)	LK7	4.3.2	$°C^{-1}$	Effect of litter temperature on litter decay rate
P(6,3)	LRESPSCALE	4.3.2	no units	Dimensionless scaler for litter respiration function
P(8,1)	GAMMA[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,2)	ALPHA1[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,3)	BETA1[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,4)	ALPHA2[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,5)	BETA2[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(8,6)	ALPHA3[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,7)	BETA3[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,8)	ALPHA4[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,9)	BETA4[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,10)	--	--		
P(8,11)	--	--		
P(8,12)	PALATABILITY	4.3.3.1	%	Palatability of non-green plant biomass
P(8,13)	ANABOLISM	4.3.3.1	%	Efficiency of converting energy to body tissue
P(8,14)	CATABOLISM	4.3.3.1	%	Efficiency of converting body tissues to energy
P(8,15)	CRITICALLOSS	4.3.3.1	%	Percent of body weight which can be lost before death
P(8,16)	BODYTEMP[M]	4.3.3.1	°C	Average body temperature of M-th fauna class
P(8,17)	ADULTWEIGHT[O]	4.3.3.1	g	Maximum weight of adult of a species of O-th sex
P(8,18)	CALORIES	4.3.3.1	cal g^{-1}	Caloric content of a species by dry weight
P(8,19)	DIGESTION	4.3.3.1	%	Digestability of a species
P(8,20)	PREF[P]	4.3.3.1	%	Relative preference of a species by a consumer species during the P-th season
P(8,21)	BIRTHWEIGHT	--	g	Biomass of newly born
P(8,22)	MAXFATPCT	4.3.3.1	%	Maximum percent fat in a healthy adult
P(9,1)	BEGINBIRTH	4.3.3.2	Julian date	Beginning date of population birth period
P(9,2)	ENDBIRTH	4.3.3.2	Julian date	Ending date of population birth period
P(9,3)	SUCCESS	4.3.3.2	%	Percent of mature females bearing surviving young
P(9,4)	YOUNGBORN	4.3.3.2	numbers	Average number of young born to a mature female
P(9,5)	MATUREAT[N]	4.3.3.2	days	Duration of time before an individual ages to next N-th age class
P(9,6)	MORTALITY[N,P]	4.3.3.2	%	Percent of population dying from natural causes for the N-th age class and P-th season
P(9,7)	DAILYRANGE	4.3.3.2	km	Radius of daily home range traveled by specie
P(9,8)	CRITICALDEPTH	4.3.3.2	cm	Critical threshold snow depth which restricts species movement
P(9,9)	MOVEIMPETUS [SNOW]	4.3.3.2	%	Relative importance of snow condition in initiating species movement
P(9,10)	MOVEIMPETUS [TEMP]	4.3.3.2	%	Relative importance of temperature condition in initiating species movement
P(9,11)	MOVEIMPETUS [COVER]	4.3.3.2	%	Relative importance of cover condition in initiating species movement
P(9,12)	MOVEIMPETUS [FOOD]	4.3.3.2	%	Relative importance of food condition in initiating species movement
P(9,13)	MOVEIMPETUS [PREVPOP]	4.3.3.2	%	Relative importance of population condition in initiating species movement
P(9,14)	PREDLOSS[N]	4.3.3.2	%	Percent of total species predation losses from the N-th age class
P(9,15)	HIBERNATION. START	4.3.3.2	julian date	Julian date for initiation of hibernation
P(9,16)	HIBERNATION. STOP	4.3.3.2	julian date	Julian date for termination of hibernation

Table 3.2. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(10,1)	ASPECT	4.2.4	direction	Direction of slope of soil surface
P(10,2)	SLOPE	4.2.4	%	Degree of incline of soil surface
P(10,3)	ALBEDO	4.2.4	%	Reflectivity of bare soil
P(10,4)	LAYER[J] .THICKNESS	4.2.4	m	Thickness of J-th soil layer
P(10,5)	LAYER[J].CLASS	4.2.4	attribute	Soil-class category of J-th soil layer
P(10,6)	ELEVATION	4.2.4	feet	ERU elevation
P(10,7)	LAYER[J].HUMUS	4.2.4	%	Soil organic matter of J-th soil layer
P(10,8)	PANDEPTH	4.2.4	cm	Depth to duripan or bedrock, whichever is first
P(10,9)	LAYER[J].STONES	4.2.4	%	Percent stones, cobbles, and gravel in J-th soil layer
P(10,10)	BASEFERTIL	4.3.3	no units	Nominal site fertility
P(C,1)	TEMPLAPSE	4.1.2	% $(1000\ ft)^{-1}$	Temperature lapse rate per 1000 ft. change in elevation, based on degrees K
P(C,2)	TEMPINTERCEPT	4.1.2	%	Intercept for temperature lapse rate regression, based on degrees K
P(C,3)	RAINLAPSE	4.1.2	% $(1000\ ft)^{-1}$	Rain lapse rate per 1000 ft. change in elevation
P(C,4)	RAININTERCEPT	4.1.2	%	Intercept for rain lapse rate regression
P(C,5)	PSOLAR1	4.1.2	no units	Regression coefficient for evaporation to predict solar radiation in mm of equivalent evaporation
P(C,6)	PSOLAR2	4.1.2	no units	Regression coefficient for wind to predict solar radiation in mm of equivalent evaporation
P(C,7)	PSOLAR3	4.1.2	no units	Regression coefficient for temperature to predict solar radiation in mm of equivalent evaporation
P(C,8)	PSOLAR4	4.1.2	no units	Regression intercept to predict solar radiation in mm of equivalent evaporation
P(C,9)	PEVAP1	4.1.2	no units	Regression coefficient for solar radiation to predict pan evaporation in mm
P(C,10)	PEVAP2	4.1.2	no units	Regression coefficient for wind to predict pan evaporation in mm
P(C,11)	PEVAP3	4.1.2	no units	Regression coefficient for mean air temperature to predict pan evaporation in mm
P(C,12)	PEVAP4	4.1.2	no units	Regression intercept to predict pan evaporation in mm

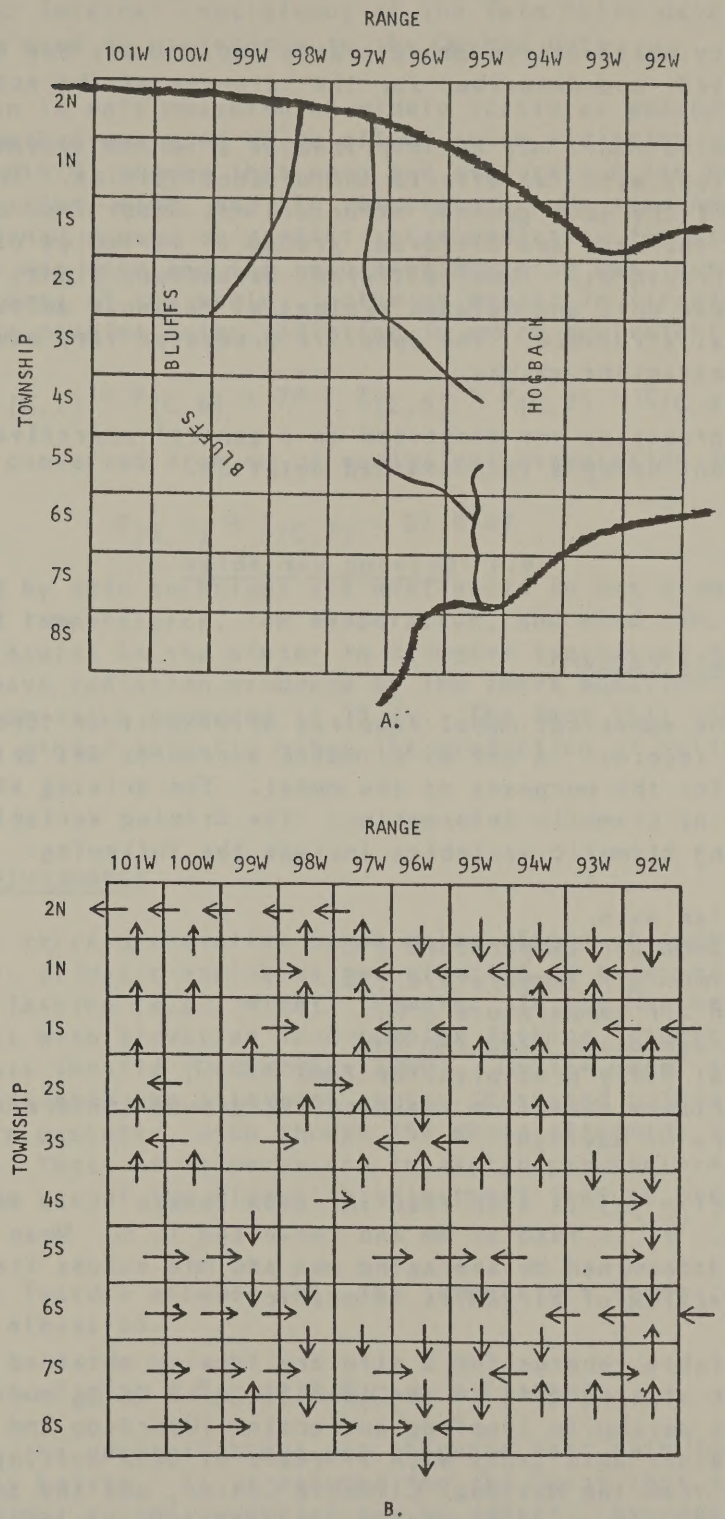


Figure 3.5. Model structure for inter-township water flow. A. Major topographic features of a basin. B. Model representation of water flow in the basin.

4. SAGEGRASS MODEL FUNCTION

The diversity which exists among plants and animals has been spatially divided, classified, and described for the purposes of the ecosystem model.

The implemented model may be described as a forced system of nonlinear difference equations with lag effects and discontinuities. The model is canonical in form; the same general structure may occur from one ecological response unit to the next and different groups of variables of the same class have identical structures. Thus, different herbaceous plants within an ecological response unit and between ecological response units would have the same compartmental structure. The specific processes vary due to different parameter and coefficient values.

Individual processes are described in a general narrative and through algebraic equations using a standardized notation.

4.1 Driving Variables

4.1.1 Base Climate Pattern

Operating the numerical model requires driving it or forcing it with driving variable records. A set of climatic variables was selected that was just sufficient for the purposes of the model. The driving variable records are daily values of climatic information. The driving variable records of naturally occuring climatic variables include the following:

$Z_{(C,1)}$ Julian date
$Z_{(C,2)}$ Maximum air temperature (°C)
$Z_{(C,3)}$ Minimum air temperature (°C)
$Z_{(C,4)}$ Mean air temperature (°C)
$Z_{(C,5)}$ Average daily wind (km day^{-1})
$Z_{(C,6)}$ Total daily precipitation (cm)
$Z_{(C,7)}$ Shortwave radiation reaching the ground (before reflection) (ly)
$Z_{(C,8)}$ Hours of daylight

Pan evaporation ($I_{(C,1)}$) is also read in, even though it is not strictly a driving variable. It is read as mm and converted to m. Mean daily air temperature was determined by averaging max and min values from the original data during conversion of all units to metric.

Driving variable records for a site are ideally obtained by interpolating available weather station data to the specific site being modelled using a technique such as parabolic leapfrog correction (Guardado and Sommers 1977). However, with weather data tapes with 11 years of data costing approximately $130 per station from the National Climatic Center, and the additional cost of interpolating many values, such a procedure was deemed infeasible. If data is more available and/or the interpolated data set will be used for many runs, then interpolation is desirable. For the Garat study, two stations were used, Owyhee, Nevada and Twin Falls, Idaho. Owyhee was closest to the site. Evaporation and wind were obtained from Twin Falls to supplement the Owyhee data. Wind was apparently not recorded during the winter when evaporation was

absent. The greater internal consistency of the Twin Falls data eventually dictated that it be used in preference to the Owyhee data.

Solar radiation is only measured at widely scattered weather stations. For this reason a method was used which allows solar radiation to be predicted. Capiel (1970) showed that open pan evaporation can be predicted based on solar radiation, wind, and air temperature. He reasoned that this process could be turned around to predict solar radiation for stations not measuring it. This was done and the resulting equation was found to be highly reliable for many parts of the world, including desert in Israel. This equation was used to predict solar radiation in mm of equivalent evaporation:

$$Z_{(C,7)} = P_{(C,5)} \cdot I_{(C,1)} + P_{(C,6)} \cdot 24 \cdot Z_{(C,5)} + P_{(C,7)} \cdot Z_{(C,4)} + P_{(C,8)}$$

This value is then converted from mm of equivalent evaporation to Langleys:

$$Z_{(C,7)} = Z_{(C,7)} \cdot 51.9747$$

The values produced by this technique are most valid in hot climates. The combination of cold temperatures, low evaporation, and wind can, however, produce anomalous results in the winter in climates typical of sagebrush. For this reason, shortwave radiation produced by the above equation is constrained such that the minimum value produced is 75 ly. The fact that wind was not measured during the winter actually makes the prediction of solar radiation better.

4.1.2 Elevation Adjustments

In mountainous terrain elevation has a major effect on local temperatures and rainfall. Other climatic variables are affected to a lesser degree or in a less predictable fashion (e.g., wind). However, in the Northern Rockies, topography interacts with elevation in a complex fashion, rendering simple elevation adjustments invalid (Daubenmire 1980). On the Garat allotment, air rising over mountains near the allotment causes increased rainfall on the northern and eastern pastures, even though the whole allotment is essentially the same elevation. Thus, it is necessary to assign pseudoelevations to each pasture to allow the use of the elevation adjustment feature present in the model.

The adjustment feature assumes that the temperature lapse rate is a linear function of elevation.

$$I_{(C,3)} = P_{(C,1)} + P_{(C,2)} \cdot P_{(10,6)}$$

This equation gives the percent change per thousand feet gain for temperatures expressed in degrees kelvin. It is assumed for the Garat that temperature differences are minimal so this equation has no effect. Average yearly rainfall for the Garat ranges from 21.59 cm in the southwest to 36.83 cm in the east and north. If we model this as being due to a 500 foot elevation difference, we obtain the values in Table 8.1 for $P_{(C,3)}$ and $P_{(C,4)}$.

$$I_{(C,2)} = P_{(C,3)} + P_{(C,4)} \cdot P10,6)$$

If no temperature or rainfall lapse rates are desired, $P_{(C,1)}$ and $P_{(C,3)}$ should be set equal to 1.0 and $P_{(C,2)}$ and $P_{(C,4)}$ set equal to 0.0. Similarly, total rainfall may be increased by setting $P_{(C,1)}$ greater than 1.0. In this way, also, water seepage into an ERU can be simulated by increasing the elevation.

The potential evaporation (pan evaporation, $I_{(C,1)}$) can vary with air temperature for each ERU. The equation used to adjust evaporation is (Capiel 1970):

$$Z_{(C,7)} = 0.001 \cdot (P_{(C,9)} \cdot Z_{(C,7)} \div 51.9747 + P_{(C,10)} \cdot Z_{(C,5)} + P_{(C,11)} \cdot Z_{(C,4)} + P_{(C,12)})$$

where 0.001 converts mm to m and 51.9747 converts mm of evaporation to langleys.

4.2 Abiotic Processes

4.2.1 Soil Temperature

The currency is calories. Temperature, in degrees centigrade, is calculated based upon volumetric heat capacities. The processes considered include the following, as diagrammed in Fig. 3.1:

1) Shortwave radiation
2) Net longwave radiation
3) Vaporization loss from soil surface
4) Heat conduction from soil layer i to layer j

Heat may enter or leave the system through three separate processes. Two of these processes, shortwave radiation and longwave radiation, influence the temperature of the surface soil, while deep conduction influences the lower soil layer temperature.

Shortwave Radiation. Shortwave radiation is considered to be that shortwave radiation which is absorbed by the surface soil. Therefore, reductions are made in the total incoming shortwave radiation due to the soil albedo and floral cover (Fig. 4.1b).

$$F_{(1,1)} = Z_{(C,7)} \cdot (1 - P_{(10,3)}) \cdot (1 - (I_{(3,13)} \cdot P_{(1,5)}))$$

Vaporization. Vaporization refers to the heat lost from the surface soil due to evaporation of soil water (Fig. 4.1c). The amount of energy required for vaporization is assumed to be directly related to the daily mean air temperature (Masterton 1969).

$$F_{(1,2)} = F_{(2,7)} \cdot [P_{(1,11)} + P_{(1,12)} \cdot Z_{(C,3)}]$$

Longwave Radiation. Longwave radiation from the surface soil is a function of the daily mean air temperature and the temperature of the surface soil (Fig. 4.1a). If the soil is cooler than the air, the soil will lose heat in the form of longwave radiation. Otherwise, the soil will gain heat. It is assumed that the earth acts as a constant grey body (de Vries 1975, Van Wijk 1963).

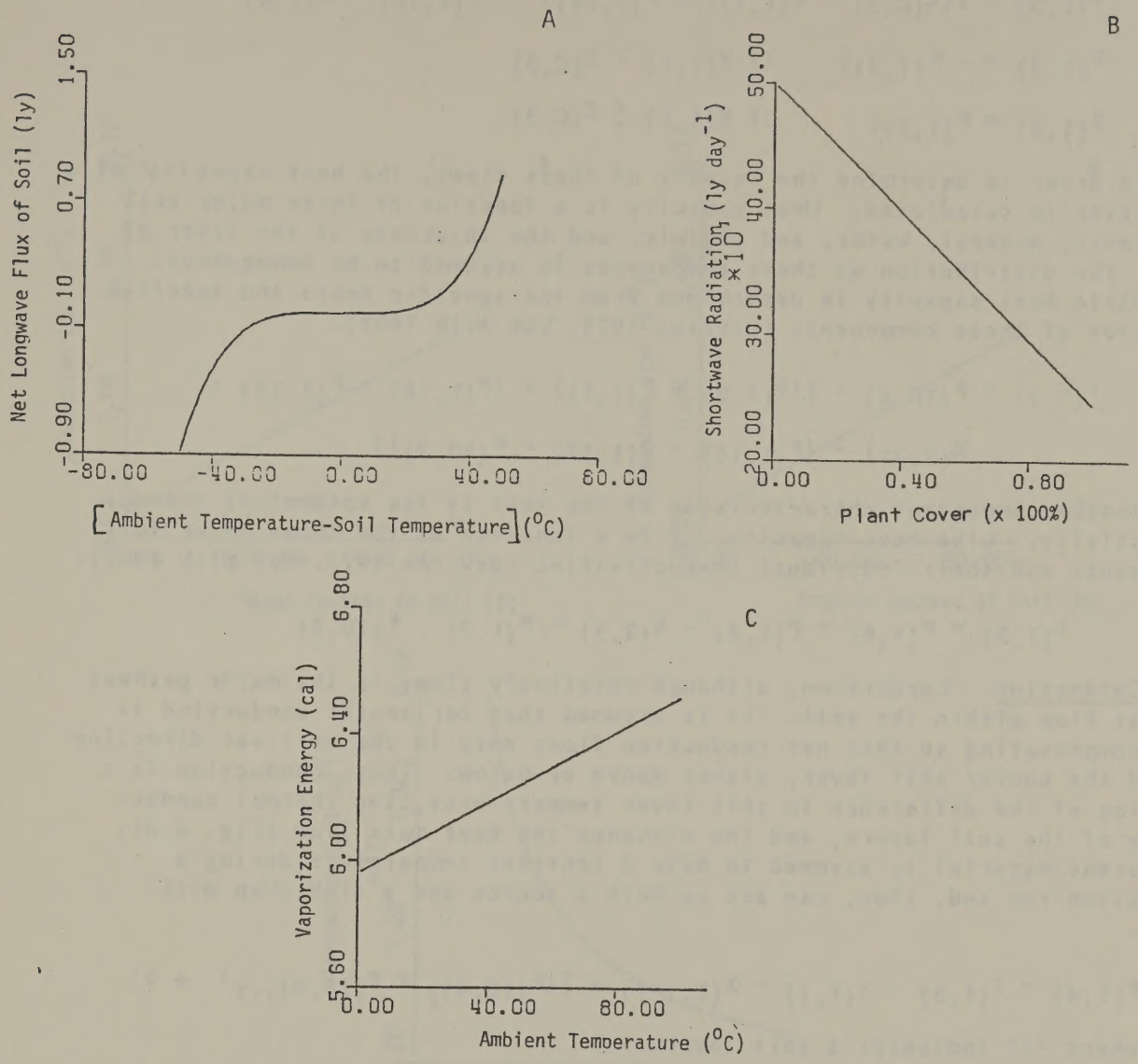


Figure 4.1. Major pathways of heat entering or exiting the surface soil layer. a) Longwave radiation as a function of the difference between the soil temperature and the ambient temperature b) Shortwave radiation reduced by plant cover c) Vaporization energy as a function of ambient temperature.

$$F_{(1,3)} = [(Z_{(C,3)} - X_{(1,1)}) + P_{(1,13)}]^4 \cdot P_{(1,10)} \cdot P_{(1,4)}$$

$$F_{(1,3)} = -F_{(1,3)}; \quad \text{if } X_{(1,1)} > Z_{(C,3)}$$

$$F_{(1,3)} = F_{(1,3)}; \quad \text{if } X(1,1) \leq Z_{(C,3)}$$

In order to determine the results of these flows, the heat capacity of a soil layer is calculated. Heat capacity is a function of three major soil components; mineral, water, and organic; and the thickness of the layer of soil. The distribution of these components is assumed to be homogenous. Volumetric heat capacity is determined from the specific heats and specific densities of these components (deVries 1975, Van Wijk 1963).

$$I_{(1,1)} = P_{(10,4)} \cdot [(P_{(1,2)} \cdot P_{(1,1)}) + (P_{(1,14)} \cdot P_{(1,15)} \cdot X_{(2,3)}) + (P_{(1,16)} \cdot P_{(1,17)} \cdot P_{(10,7)})]$$

Another important characteristic of the soil is its volumetric thermal conductivity. Like heat capacity, it is a function of the three major soil components and their individual conductivities (deVries 1975, Van Wijk 1963).

$$I_{(1,2)} = P_{(1,6)} + P_{(1,8)} \cdot X_{(2,3)} + P_{(1,7)} \cdot P_{(10,7)}$$

Conduction. Conduction, although relatively slow, is the major pathway of heat flow within the soil. It is assumed that horizontal conduction is self-compensating so that net conduction flows only in the vertical direction toward the cooler soil layer, either above or below. Thus, conduction is a function of the difference in soil layer temperatures, the thermal conductivity of the soil layers, and the distance the heat must flow (Fig. 4.2). The parent material is assumed to have a constant temperature during a simulation run and, thus, can act as both a source and a sink (Van Wijk 1963).

$$F_{(1,4)} = I_{(1,2)} \cdot X_{(1,j)} - X_{(1,j+1)} \div [(P_{(10,4)_j} + P_{(10,4)_{j+1}}) \div 2]$$

where "j" indicates a soil layer.

The temperature of any soil layer is a function of its previous temperature, the net flux and the heat capacity of the entire layer (Van Wijk 1963). For soil layers below the surface, $F_{(1,1)}$, $F_{(1,2)}$ and $F_{(1,3)}$ equal zero.

$$X_{(1,1)_{t+1}} = X_{(1,1)_t} + [(F_{(1,1)} + F_{(1,2)} - F_{(1,3)} - F_{(1,4)}) \div (I_{(1,1)} \cdot P_{(10,4)})]$$

where "t" indicates a time step.

4.2.2 Soil Moisture

The currency is meters (or cubic meters) of water. The processes considered include the following, as diagrammed in Fig. 3.1:

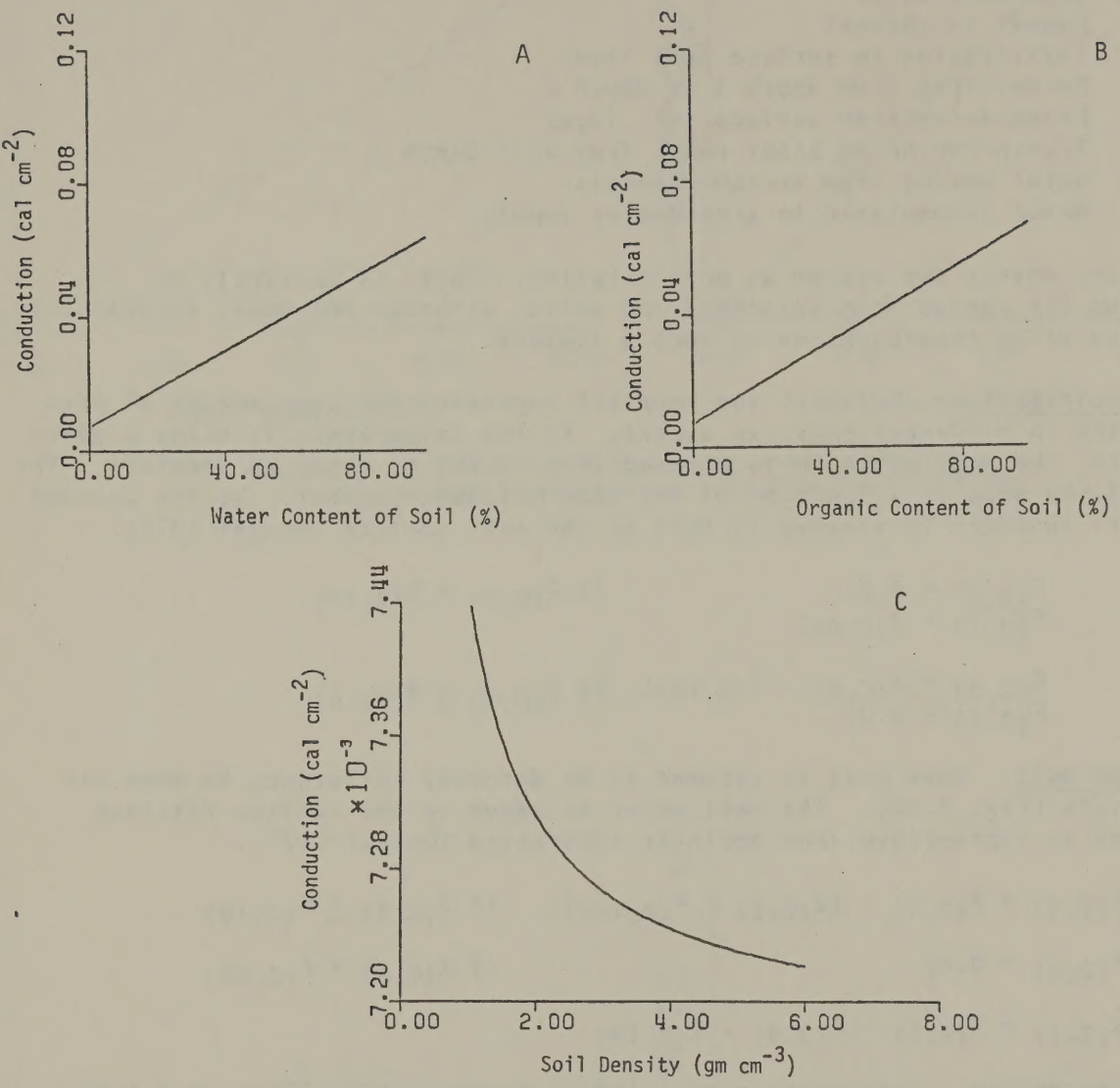


Figure 4.2. Effects of soil components upon heat conduction through the soil. a) Volumetric water content b) Volumetric organic matter content c) Density of soil mineral content.

1) Total daily rainfall
2) Rainfall intercepted by plants
3) Total daily snowfall
4) Snow melt water
5) Runoff to channel
6) Infiltration to surface soil layer
7) Percolation from depth i to depth j
8) Evaporation from surface soil layer
9) Transpiration by plant roots from soil depth i
10) Water moving from stream channels
11) Water accumulator in groundwater supply

Water enters the system as precipitation. There is currently no provision for run-on from adjacent land units, although the model structure is set up to allow incorporation of such a feature.

Precipitation. Rainfall and snowfall represent the same amount of precipitation in different physical states. If the temperature is below a given threshold, the precipitation is assumed (Fig. 4.3b) to occur as snowfall. The depth of the snow is a function of the snow moisture content. At the current time, all snowfall is assumed to fall on the soil surface (Dougal 1971).

$$F_{(2,3)} = 0.0; \qquad \text{if } Z_{(C,3)} > P_{(2,14)}$$
$$F_{(2,1)} = Z_{(C,6)};$$

$$F_{(2,3)} = Z_{(C,6)} \cdot P_{(2,13)}; \qquad \text{if } Z_{(C,3)} \leq P_{(2,14)}$$
$$F_{(2,1)} = 0.0;$$

Snow melt. Snow melt is assumed to be directly influenced by mean air temperature (Fig. 4.3a). The melt water is added to the surface retained water and an appropriate snow depth is subtracted (Dougal 1971).

$$F_{(2,4)} = P_{(2,9)} \cdot (Z_{(C,3)} - P_{(2,10)}); \qquad \text{if } Z_{(C,3)} \geq P_{(2,10)}$$

$$F_{(2,4)} = 0.0; \qquad \text{if } Z_{(C,3)} < P_{(2,10)}$$

$$X_{(2,1)} = X_{(2,1)} - F_{(2,4)} \cdot P_{(2,13)}$$

Interception. Interception of rainfall by vegetation (Figs. 4.4-4.8) is a function of plant cover and precipitation. Each plant category, i.e., litter, grasses, forbs, shrubs, and trees, has an assigned interception storage capacity and a coefficient of evaporation. The values of these factors were determined from regressions found in the literature. The interception storage capacity is modified by the amount of precipitation. For simplicity, snow is not intercepted at present (Zinke 1967, USFS 1968, Couturier 1973).

$$I_{(2,9)} = P_{(2,7)} \cdot (1 - \exp(- Z_{(C,6)} \div P_{(2,7)}))$$

$$F_{(2,2)} = I_{(3,13)} \cdot I_{(3,15)_r} \cdot (Z_{(C,6)} \cdot I_{(2,9)} + P_{(2,6)})$$

The majority of the water flows within the soil are functions of the soil water potential (or matric potential) and the volumetric water content of the different soil layers. The hydraulic conductivity and the hydraulic suction head potential are calculated from water potential and volumetric content.

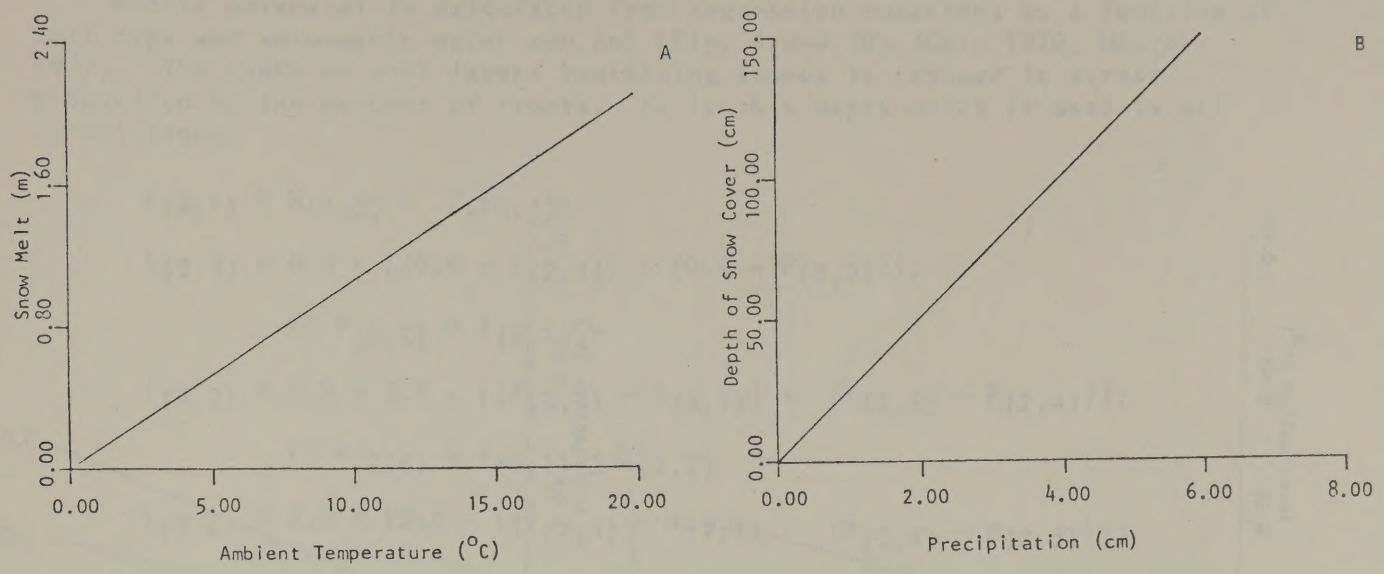


Figure 4.3. a) Snow melt as a function of ambient temperature.
b) Depth of snow cover as a function of precipitation.

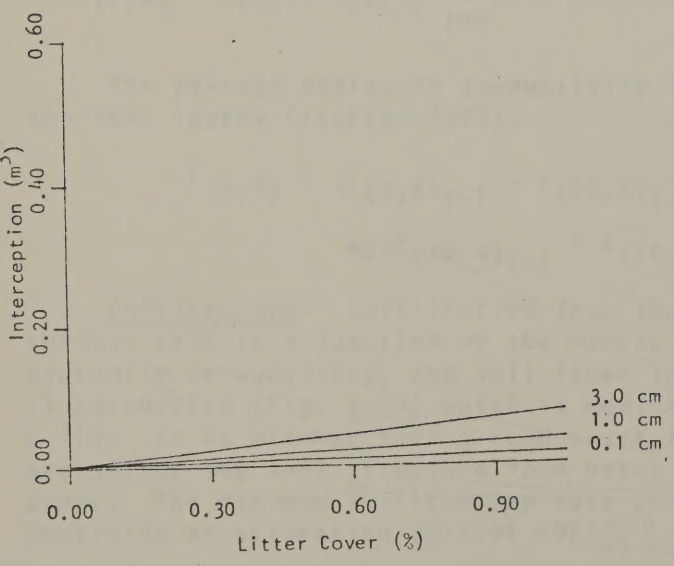


Figure 4.4. Rainfall intercepted by litter cover at three rain intensities.

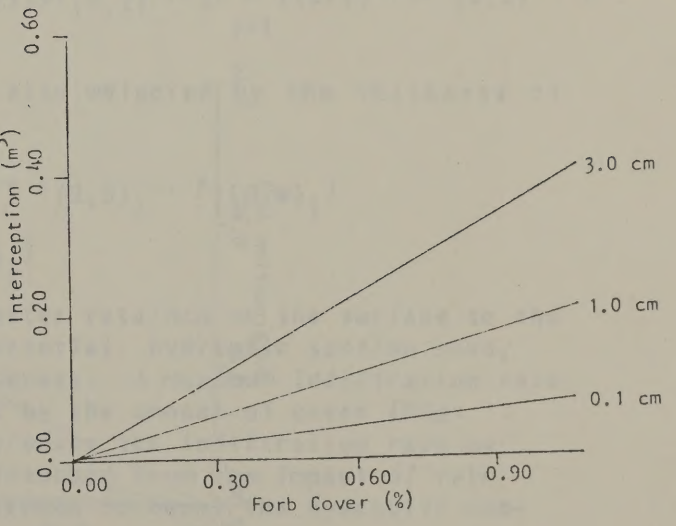


Figure 4.5. Rainfall intercepted by forb cover at three rain intensities.

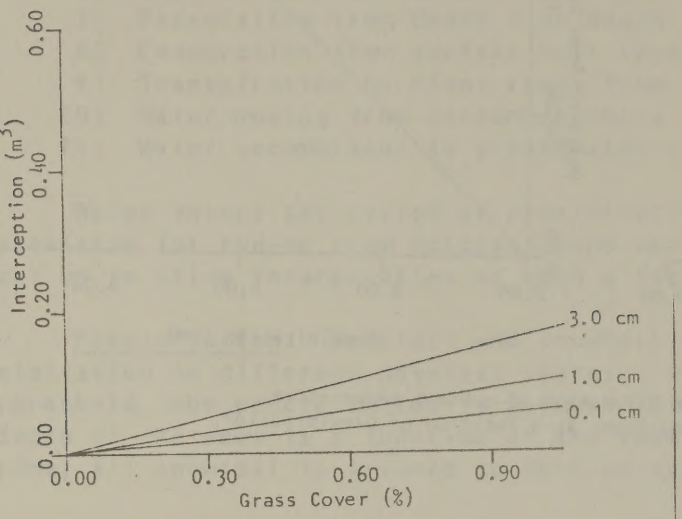


Figure 4.6. Rainfall intercepted by grass cover at three rain intensities.

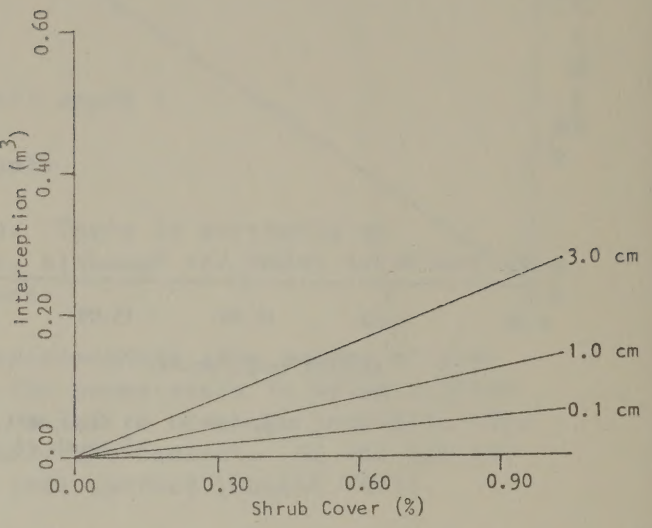


Figure 4.7. Rainfall intercepted by shrub cover at three rain intensities.

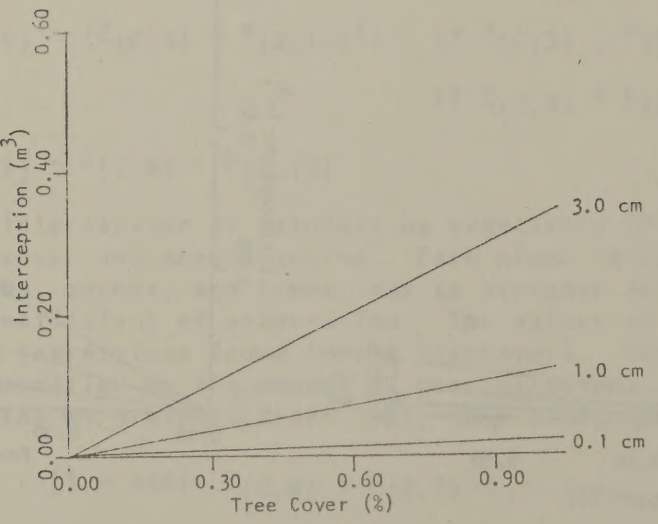


Figure 4.8. Rainfall intercepted by tree cover at three rain intensities.

Matric potential is calculated from regression equations as a function of soil type and volumetric water content (Fig. 4.9-4.10) (Cole 1976, Hillel 1977). The depth of soil layers containing stones is reduced in direct proportion to the percent of stones. It is this depth which is used in all calculations.

$$I_{(2,1)} = X_{(2,3)} \div P_{(10,4)}$$

$$I_{(2,2)} = 0.3 \cdot [(0.6 - I_{(2,1)}) \div (0.6 - P_{(2,2)})];$$

$$\text{if } P_{(2,2)} > I_{(2,1)}$$

$$I_{(2,2)} = 0.3 + 2.7 \cdot [(P_{(2,2)} - I_{(2,1)}) \div (P_{(2,2)} - P_{(2,4)})];$$

$$\text{if } P_{(2,4)} < I_{(2,1)} \leq P_{(2,2)}$$

$$I_{(2,2)} = 3.0 + 12.0 \cdot [(P_{(2,4)} - I_{(2,1)} \div (P_{(2,4)} - P_{(2,5)})];$$

$$\text{if } P_{(2,5)} < I_{(2,1)} \leq P_{(2,4)}$$

The hydraulic suction head is directly related to the soil water potential and the thickness of the soil layer (Hillel 1977).

$$I_{(2,3)} = I_{(2,2)} - P_{(10,4)}$$

The hydraulic conductivity is a function of the conductivity at saturation and the volumetric water content (Fig. 4.11). It is weighted by the water potentials of the soil layers (Hillel 1977, Van Wijk 1963).

$$I_{(2,4)} = P_{(2,1)} \cdot I_{(2,1)} \cdot \sum_{j=1}^{j} [((2 \cdot j)+1-(2 \cdot i)) \div I_{(2,2)}^{1/2}] \div \sum_{j=1}^{j} [(2 \cdot j)^{-1}) \div I_{(2,2)}^{1/2}]$$

The average hydraulic conductivity is also weighted by the thickness of the soil layers (Jackson 1972).

$$I_{(2,5)} = (I_{(2,4)_{j-1}} \cdot P_{(10,4)_{j-1}} + I_{(2,5)_j} \cdot P_{(10,4)_j}) \div (P_{(10,4)_{j-1}} + P_{(10,4)_j})$$

Infiltration. Infiltration from the water retained on the surface to the surface soil is a function of the matric potential, hydraulic suction head, hydraulic conductivity, and soil layer thickness. A maximum infiltration rate is calculated (Fig. 4.12) which is modified by the amount of cover (Fig. 4.11). It is assumed that ground cover increases the infiltration rate by preventing the soil structure from being disturbed from the impact of rain drops. The minimum infiltration rate is assumed to equal the hydraulic conductivity at saturation (Hillel 1977).

$$I_{(2,8)} = -I_{(2,3)} \cdot (P_{(2,1)} + I_{(2,4)}) \div (2 \cdot P_{(10,4)})$$

$$F_{(2,6)} = P_{(2,1)} + (I_{(3,13)})^{1/2} \cdot I_{(2,8)} - P_{(2,1)})$$

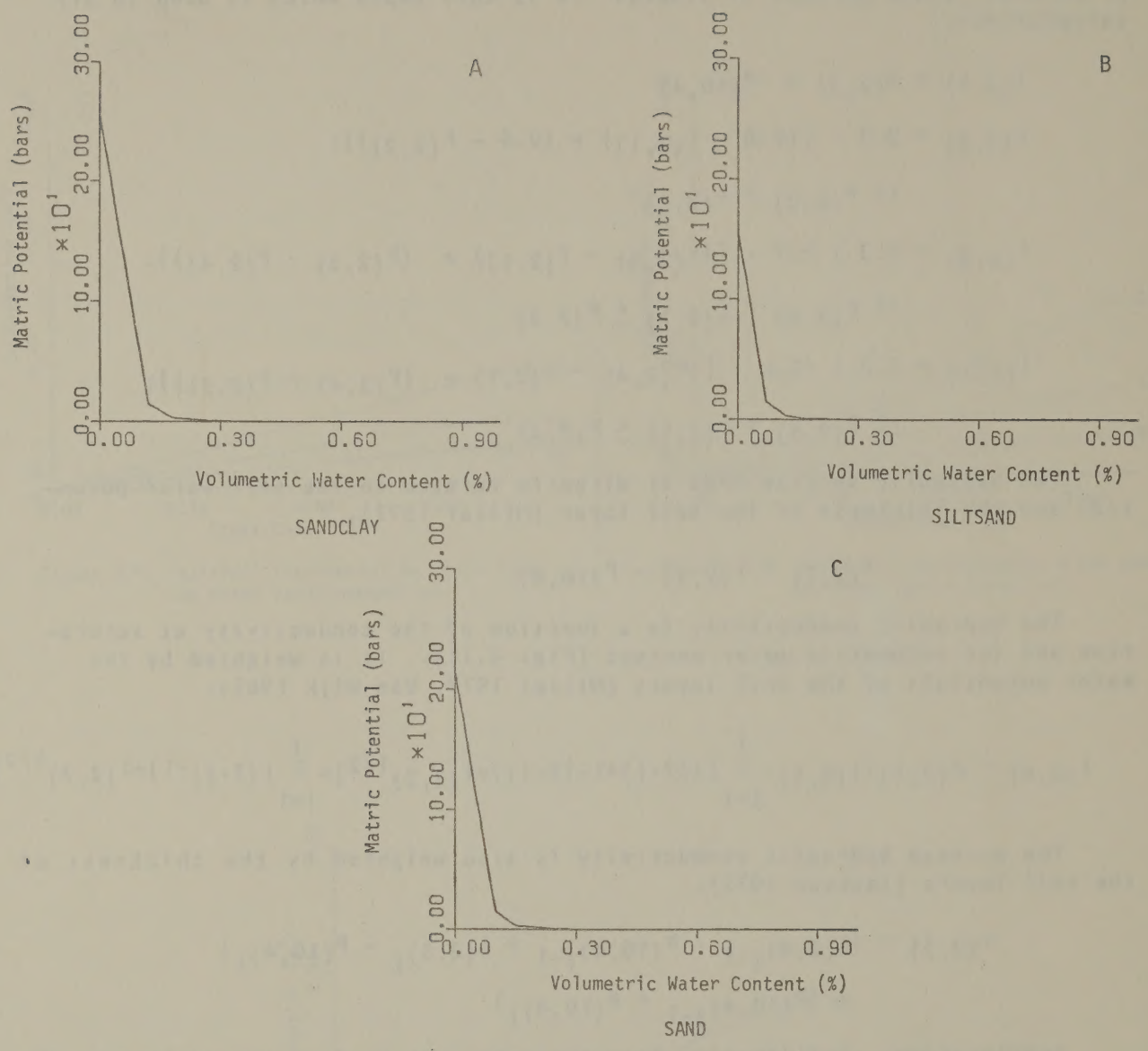


Figure 4.9. Matric potential as a function of volumetric water content for three soil types a) sandclay b) siltsand c) sand.

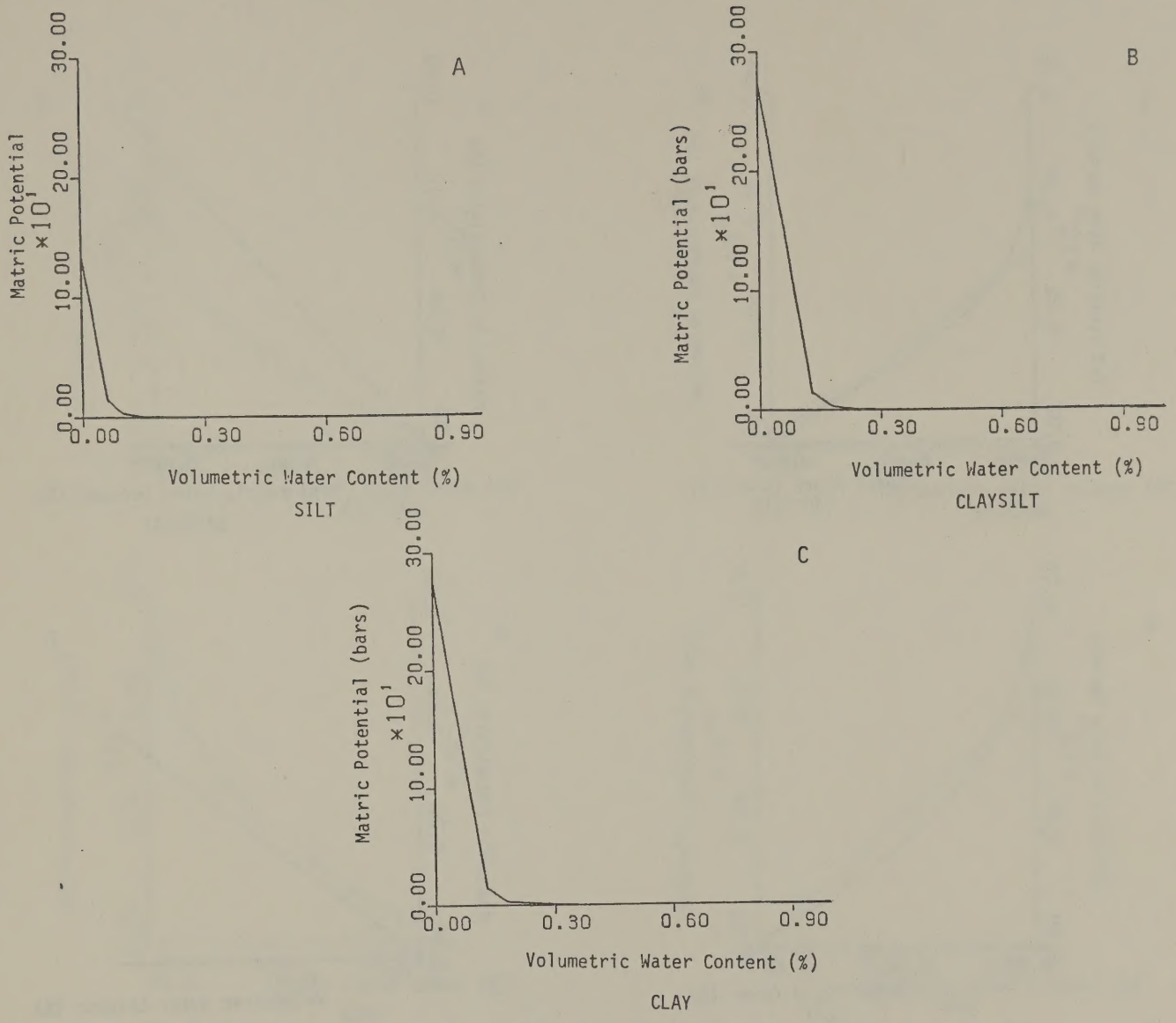


Figure 4.10. Matric potential as a function of volumetric water content for three soil types a) silt b) claysilt c) clay.

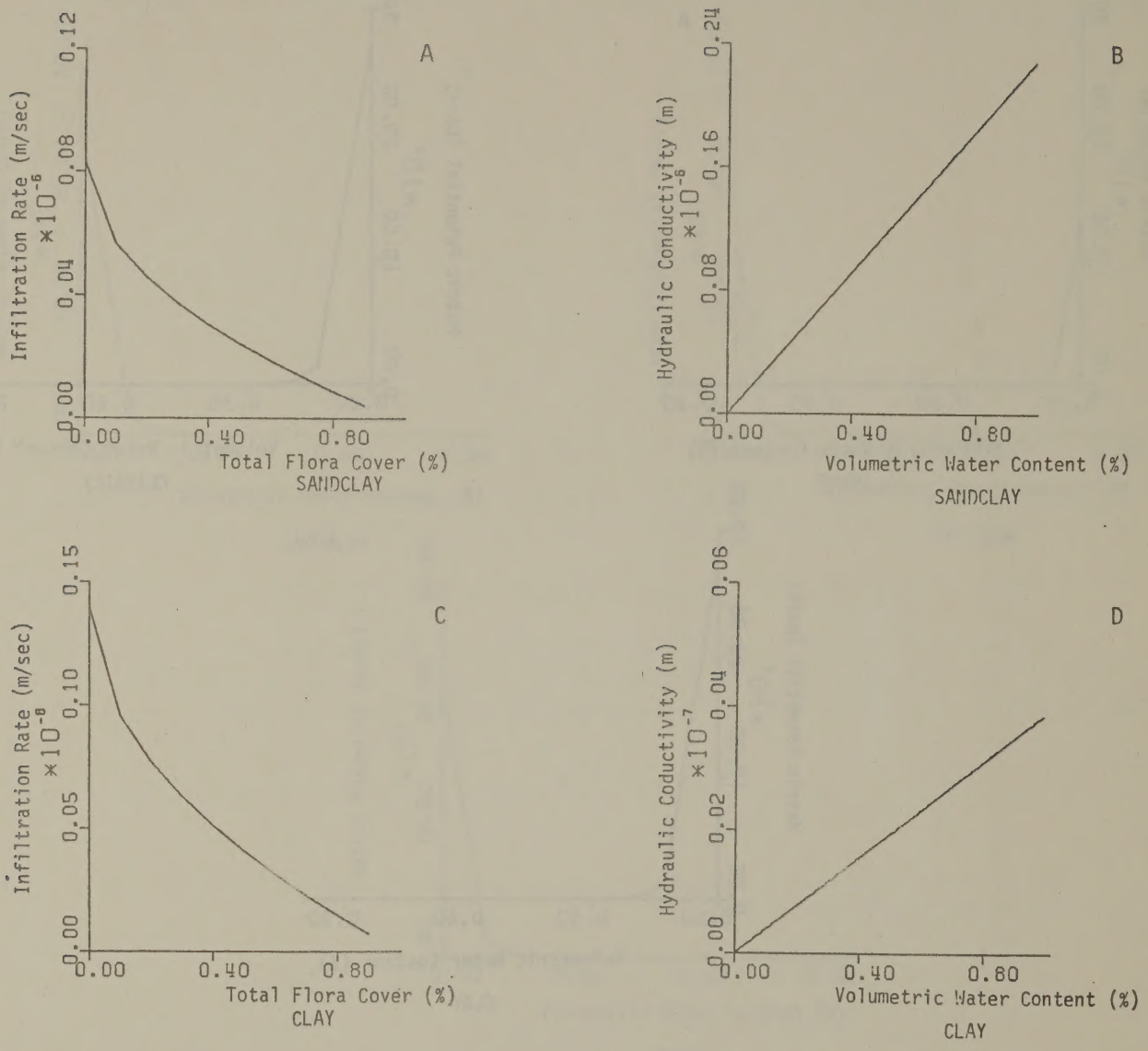
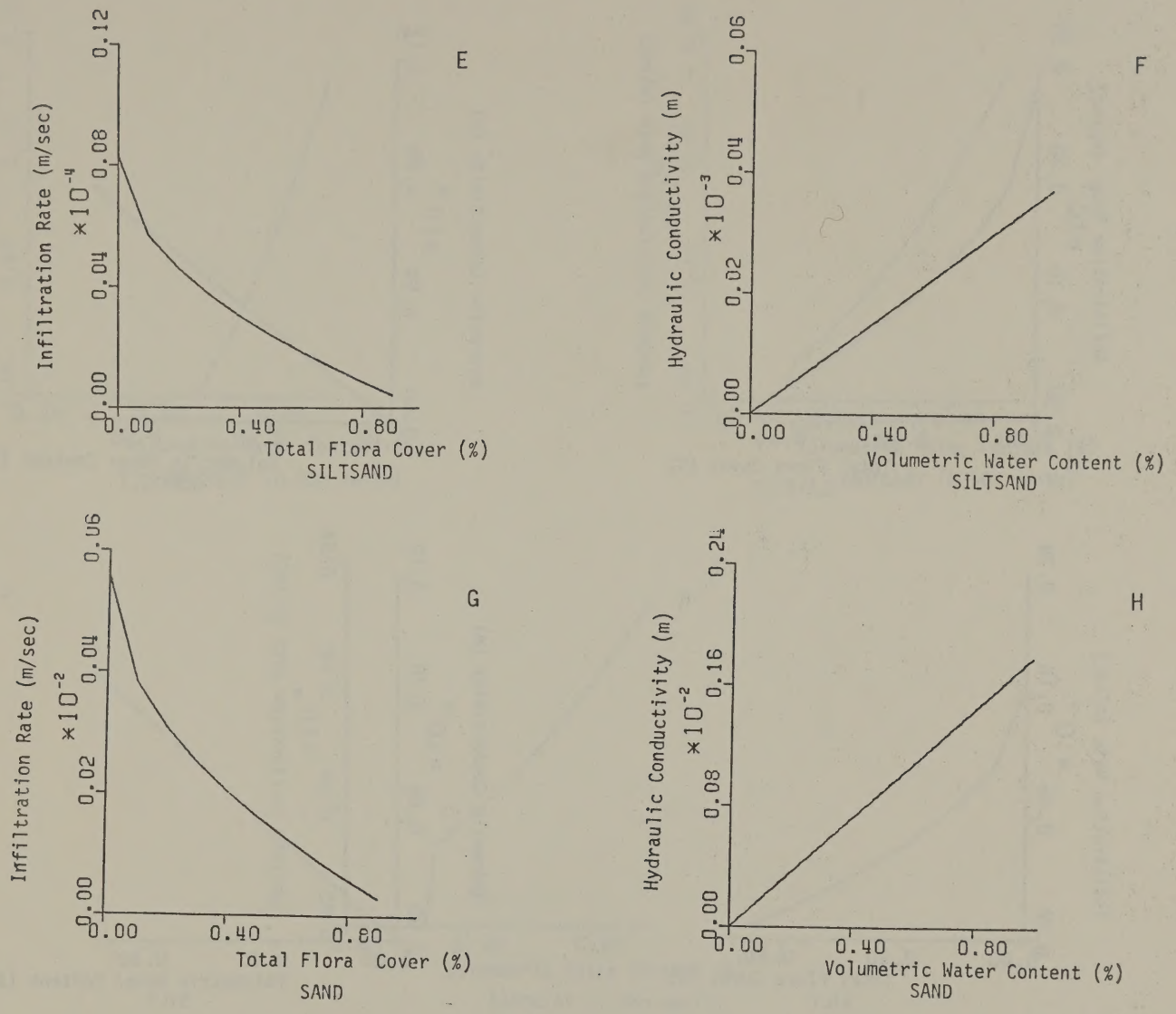


Figure 4.11. Effect of flora cover on infiltration rate and hydraulic conductivity as a function of volumetric water content for six soil types. A. Sandclay infiltration rate, B. Sandclay hydraulic conductivity, C. Clay infiltration rate, D. Clay hydraulic conductivity, E. Siltsand infiltration rate, F. Siltsand hydraulic conductivity, G. Sand infiltration rate, H. Sand hydraulic conductivity, I. Claysilt infiltration rate, J. Claysilt hydraulic conductivity, K. Silt infiltration rate, and L. Silt hydraulic conductivity.



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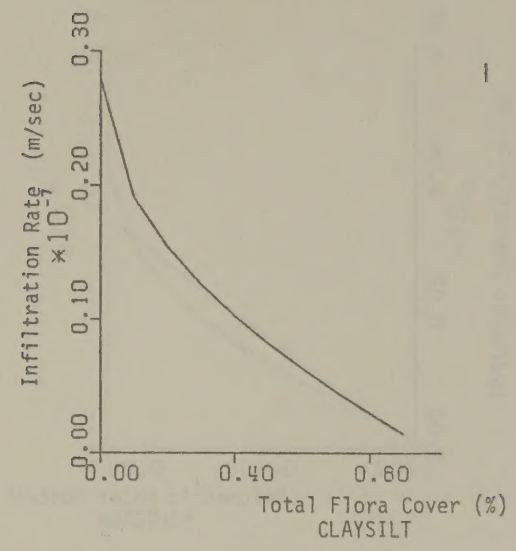

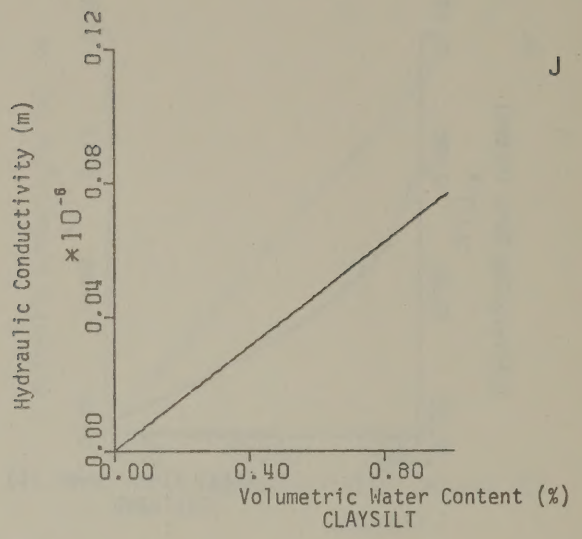

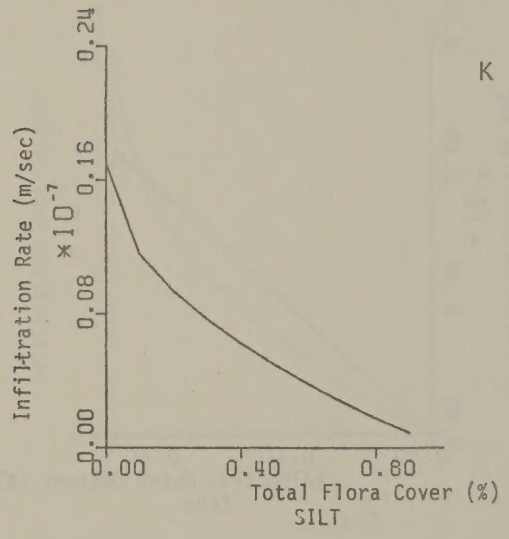

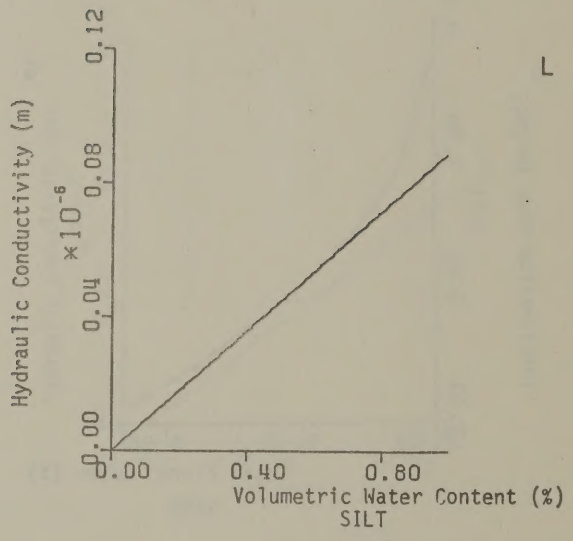

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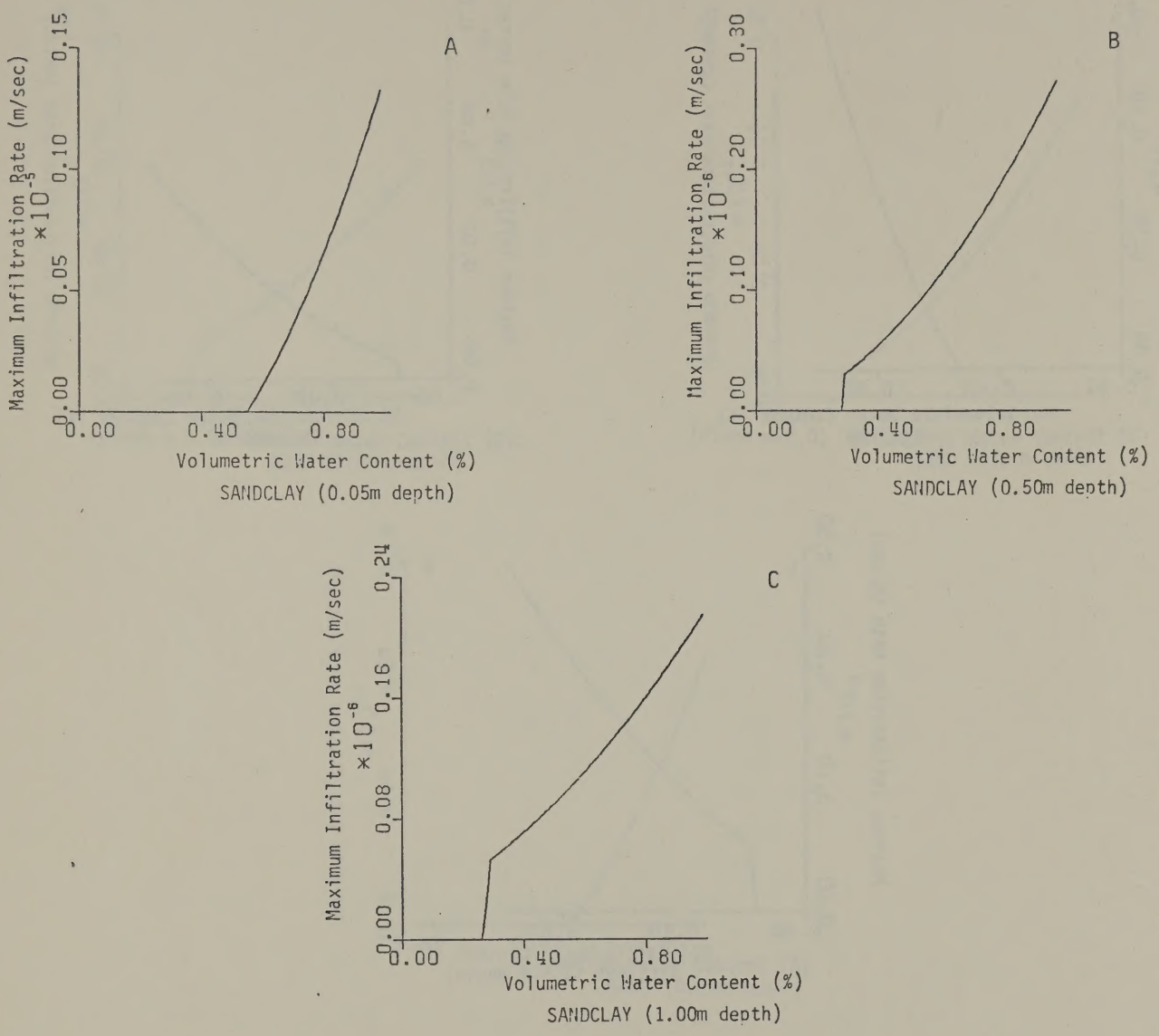
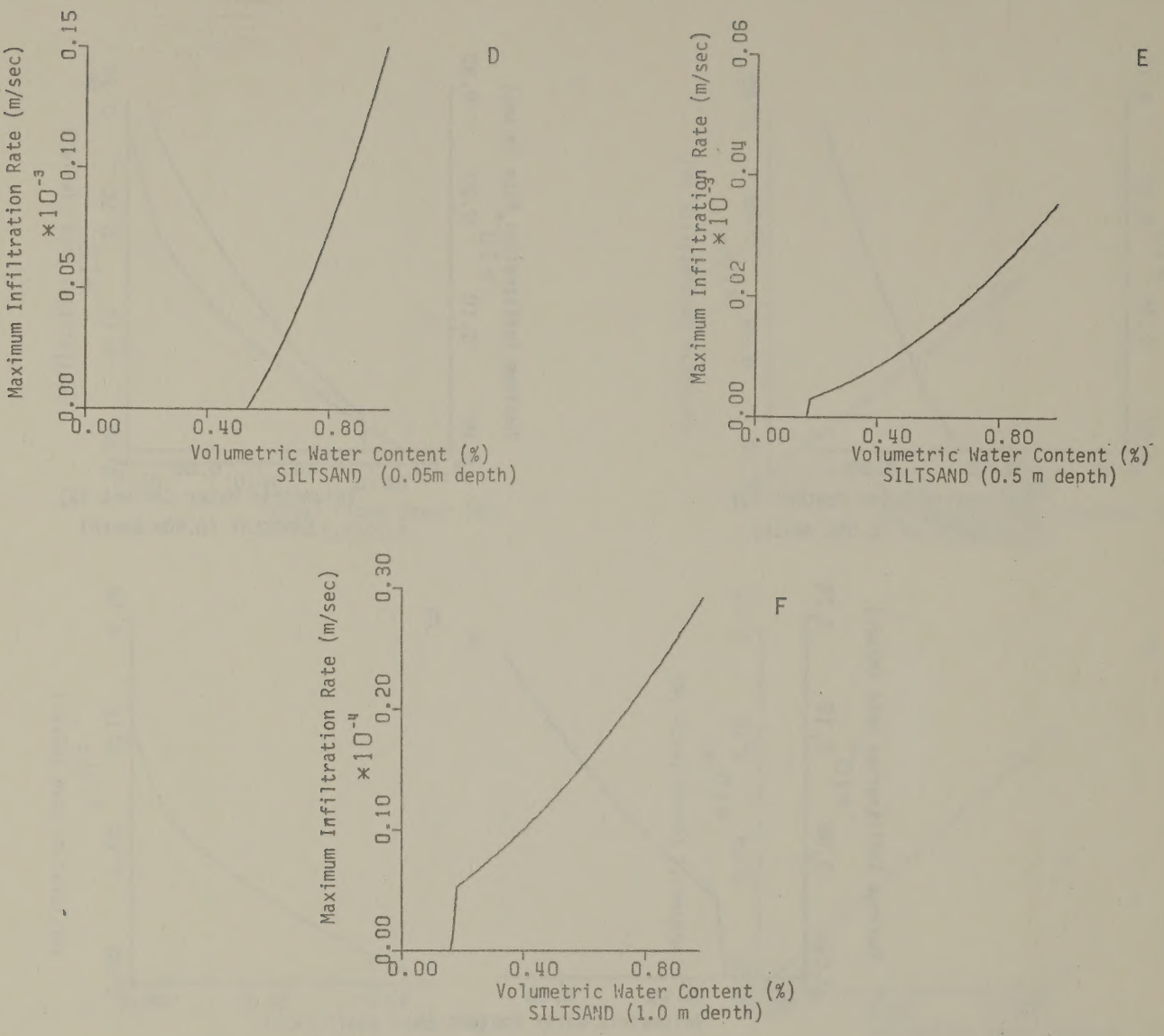


Figure 4.12. Maximum infiltration rates as a function of volumetric water content for six soil types at three soil thicknesses. A. Sandclay at 0.05 m, B. Sandclay at 0.5 m, C. Sandclay at 1.0 m, D. Siltsand at 0.05 m, E. Siltsand at 0.5 m, F. Siltsand at 1.0 m, G. Sand at 0.05 m, H. Sand at 0.5 m, I. Sand at 1.0 m, J. Clay at 0.05 m, K. Clay at 0.5 m, L. Clay at 1.0 m, M. Claysilt at 0.05 m, N. Claysilt at 0.5 m, O. Claysilt at 1.0 m, P. Silt at 0.05 m, Q. Silt at 0.5 m, and R. Silt at 1.0 m.



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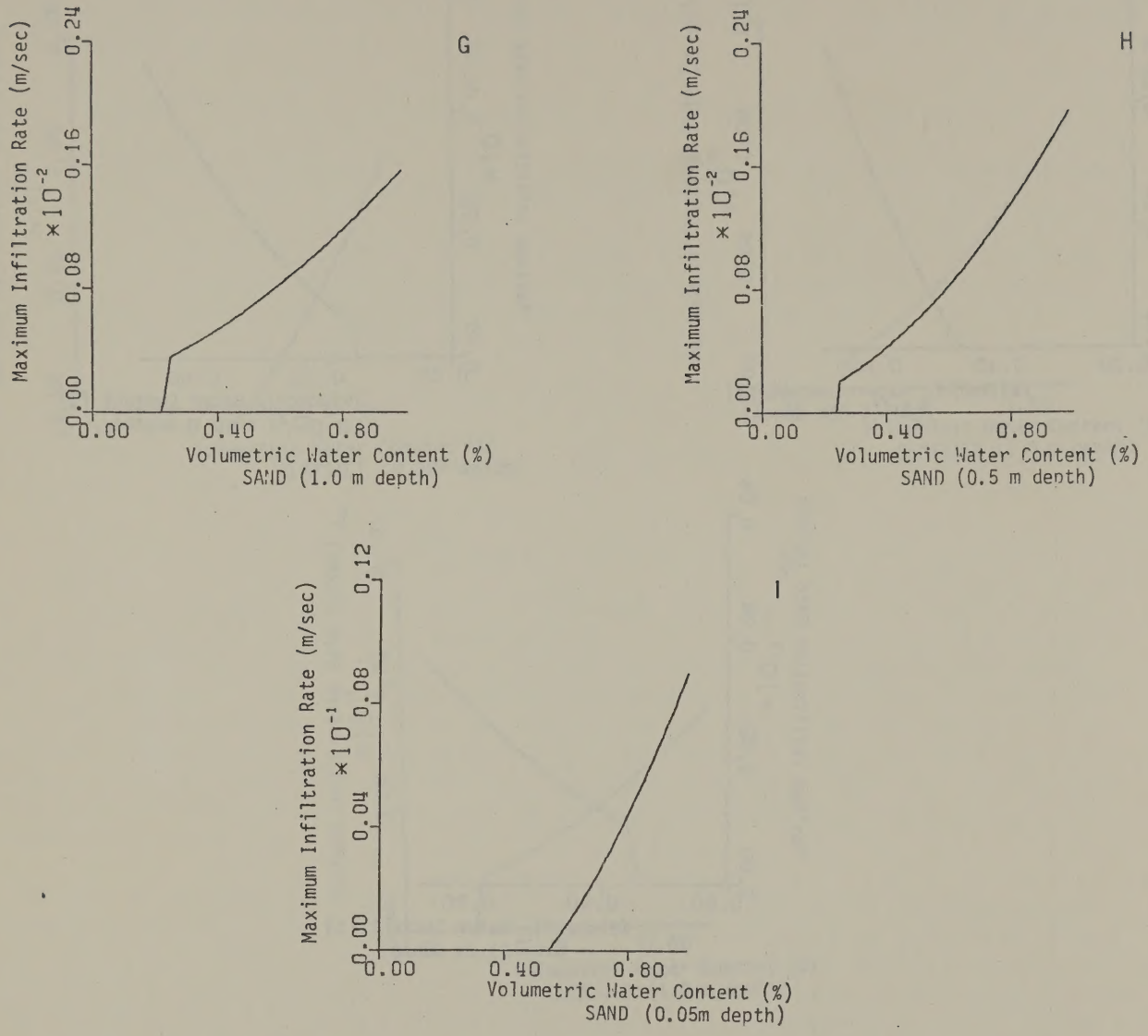

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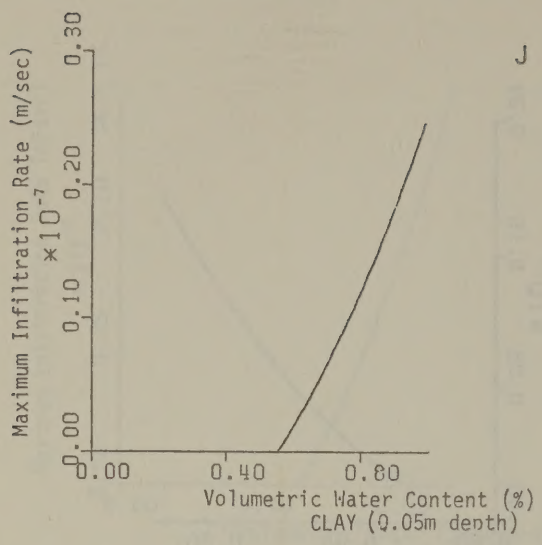

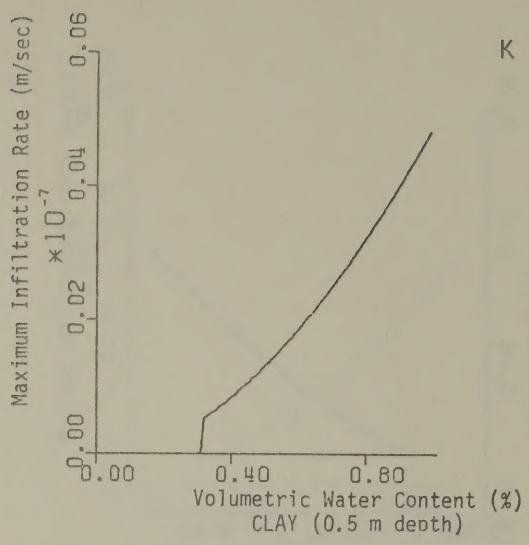

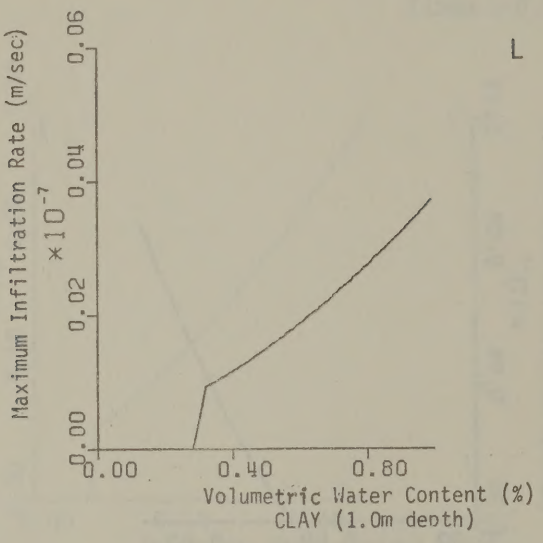

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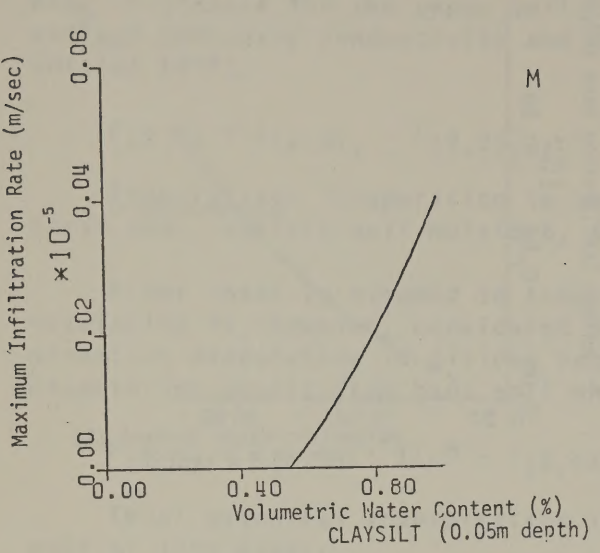

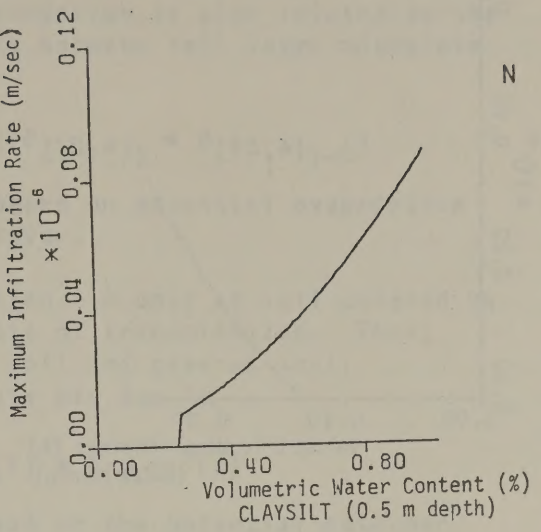

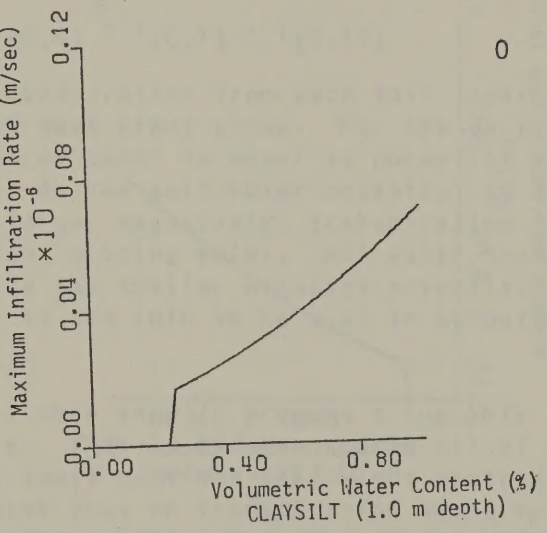

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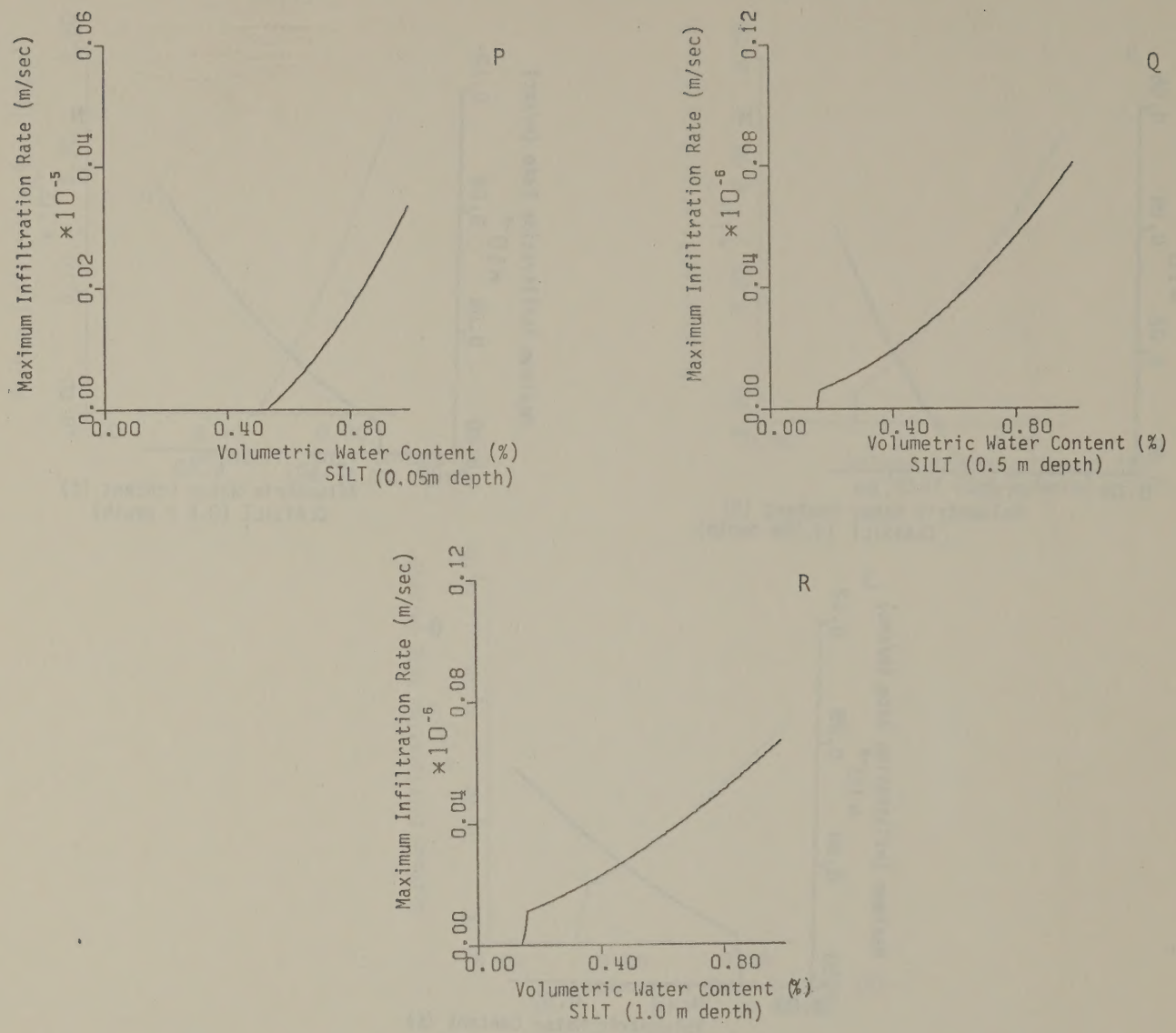

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Percolation. Percolation transfers water from one soil layer to the lower soil layer. However, it can also draw water up if the hydraulic suction head is greater for the upper soil layer. Percolation is also related to the average hydraulic conductivity and the distance between soil layer midpoints (Hillel 1977).

$$F_{(2,8)} = I_{(2,3)_j} - I_{(2,3)_{j-1}} \cdot I_{(2,5)} + ((P_{(10,4)_j} + P_{(10,4)_{j-1}})$$

Evaporation. Evaporation is calculated based on potential evaporation (open pan), surface soil moisture, and plant cover.

Plant cover is assumed to reduce evaporation. A unit of soil covered by vegetation is, however, considered to be capable of transpiration. Thus, potential evaporation is divided between bare soil and covered soil. Evaporation occurs from bare soil where the rate per day is

$$F_{(2,7)} = I_{(C,1)} \cdot (1.0 - I_{(3,13)}) \cdot (I_{(2,1)} \div P_{(2,2)}^{1/2})$$

Total potential transpiration is then based on the potential rate per unit of live cover.

$$I_{(C,4)} = I_{(C,1)} \cdot I_{(3,15)}$$

Transpiration. Transpiration from each soil layer is the sum of transpiration losses due to each plant group. For any particular group, transpiration per unit area of cover is equal to potential transpiration when water is not limiting. As the soil water potential in the wettest zone containing roots becomes larger negatively, transpiration is reduced until it becomes zero at the plant wilting point. All water transpired by a species is taken from the zone with the smaller negative potential (Detling et al. 1978). The surface soil layer is too thin to be used in computing plant potentials except for seedlings.

It is assumed that when snow is present all plants smaller than large shrubs do not transpire. This is because nearly all of such plants will be buried in snow and the small portions that might protrude would be cooled by the snow to such a degree that no transpiration would occur. Trees and large shrubs do transpire during periods with snow if the potential rate of transpiration is non-zero.

$$F_{(2,9)} = \sum_{r=1}^{R} [I_{(C,4)} \cdot I_{(3,28)_r} \cdot I_{(3,13)_r} \cdot \exp(P_{(3,4)} \cdot I_{(3,10)_r})]$$

4.3 Biotic Processes

4.3.1 Terrestrial Floral Processes

In the numerical model there are five floral currencies: tree cover, herbaceous plant biomass per unit area, shrub biomass per individual plant, numbers of shrubs per unit area, and amount of litter per unit area. The

degree of resolution varies according to the currency. For example, tree cover, litter, and shrub numbers have a coarse degree of resolution, while herbaceous plant biomass and shrub biomass have a greater degree of resolution. This greater degree of resolution is needed to model plant responses to management practices.

4.3.1.1 Variable Timesteps: The Active Days Concept

Since plants are strongly affected by climatic and abiotic variables, implementation of a timestep longer than that used in the abiotic section of the model involves averaging the relevant abiotic variables. This averaging process not only involves a loss of information but may actually be misleading. For example, if air temperatures are averaged for a week during which there are five moderately warm days and two very cold days, the resulting average may be lower than the minimum required for photosynthesis, although photosynthesis would have occurred on the five warm days but not on the cold days.

The active days concept conserves the maximum amount of information during the averaging process. Active days calculations for aboveground plant parts illustrate the concept. If the mean air temperature is above the photosynthetic minimum, the water potential in the wettest soil layer with roots is greater than the wilting point, and there is no snow, then $I_{(3,18)_v}$, $v = I_{(3,16)}$ is incremented and that day's values are added to the variables $I_{(3,19)}$, $I_{(3,20)}$, $I_{(3,21)}$, and $I_{(3,10)}$. In this way, days too extreme for photosynthesis to occur do not affect the average.

There are four counters in the model for types of days. $I_{(3,18)}$, described above, is used for photosynthesis and translocation calculations. $I_{(3,23)}$ keeps track of the number of days below the wilting point. $I_{(3,24)}$ gives the severity of the drought. This information is used in calculating mortality. $I_{(3,25)}$ keeps track of days during which soil layer j is below the wilting point. This information is used for root mortality.

In this model, the state variables are updated by adding the product of daily flows multipled by the timestep. For plants, the days of activity act as the timestep. The three types of active days result in different timesteps for different flows. For example, given a model timestep of seven days, if a cold spell results in one day warm enough for photosynthesis, while the soil is warm and wet the entire week, the flow for photosynthesis per day is multipled by one and the root mortality flows are multipled by zero.

4.3.1.2 Cover and Leaf Area

Cover and leaf area are important components of plants in the model. Cover is used to determine the proportion of potential evapotranspiration accounted for by bare soil, for allocating transpiration among species, and for calculating rainfall interception. Trees are modeled in units of cover. Cover must be calculated for other species based on leaf biomass. Regression equations were obtained from the literature. Shrub cover was taken from Rittenhouse and Sneva (1977) for sagebrush, which is used as representative of all sagebrush ecosystem shrubs:

$$I_{(3,14)} = 0.01004969433 \cdot X_{(4,4)}^{1.076426265} \cdot X_{(7,1)}$$

Cover equations for forbs and grasses are from Payne (1974). Payne's equations have been adjusted for plot size and units of cover. Live and standing dead cover are based on the same equations. Live and standing dead cover are based on the same equations.

For forbs:

$$I_{(3,14)} = 0.002 + 0.00354 \cdot X_{(3,3)}$$

For warm-season grasses:

$$I_{(3,14)} = 0.0078 + 0.0052 \cdot X_{(3,3)}$$

For cool-season grasses:

$$I_{(3,14)} = 0.0076 \cdot X_{(3,3)}$$

For cool-season annual grasses:

$$I_{(3,14)} = 0.0004 + 0.0047 \cdot X_{(3,3)}$$

For litter:

$$I_{(3,15)} = 0.005 \cdot X_{(6,1)}$$

For the cool-season grass equation the intercept was altered from -0.0034 to 0. Cover per species is then adjusted to be a percent of the total live cover, which does not exceed 100%. Total cover is cover based on live plus standing dead biomass and litter.

Leaf area is calculated as a constant percent of leaf biomass:

$$I_{(3,1)} = P_{(3,22)} \cdot X_{(3,3)}$$

Leaf area is used in photosynthesis to calculate the shading leaf area over a plant, which reduces photosynthesis. Taller plants shade lower ones and plants in the same stratum shade each other and themselves. The order of shading is: TREES > LARGE SHRUBS > FORBS = WARM-SEASON GRASS = COOL-SEASON GRASS = COOL-SEASON ANNUAL GRASS > SMALL SHRUBS.

4.3.1.3 Germination and Extinction

The model does not assume steady state conditions and the process of recovery from disturbance is modeled explicitly. This is achieved by allowing species to become established or reestablished on the site.

Germination is allowed at any time. Certain conditions must be met before germination of any species may occur. Snow must not have been present for a limited period of time prior to germination. Soil water in the surface layer must have been above the wilting point for a similar period of time. Also, temperatures must be favorable.

Once these conditions are met, the species to germinate are determined by examining the sets of parameters. It is assumed that all plants may reach all ERU's but may not necessarily be allowed to germinate. If there are any species which can inhabit the ERU but are not present, then those species will germinate. New species begin with arbitrary small amounts of biomass in the green, storage, and upper root zone categories. Trees begin with an arbitrary small amount of cover. Litter is never allowed to become extinct and thus never needs to "germinate".

Under certain conditions, plant species may become extinct within an ERU during the simulation. There are several conditions that cause extinction in the model. If the population of both size classes of shrubs is zero, the species becomes extinct. For shrubs and herbaceous species, the absence of green and storage biomass or the absence of roots removes all possibility of photosynthesis and signals extinction. Trees with zero cover also become extinct. When a plant species becomes extinct in an ERU, all woody, standing dead, and green biomass for that species is transferred to litter.

4.3.1.4 Phenology

There are three phenological states considered in the model: seedling status, dormancy, and season of leaf fall. After a species enters an ERU via the germination function, it remains a seedling for 40 days. While a plant is a seedling it has roots only in the top soil layer. In this way, the greater sensitivity of seedlings to drought is simulated in a simple manner. If the user defines the site so that the second soil layer is very deep, seedlings will not be drought sensitive, and some model realism will be lost.

Plants are dormant during the winter season, which is defined by date rather than by temperature. Dormant plants do not attempt translocation. Translocation activity is reduced by three-fourths in the autumn.

Leaf fall for shrubs is defined to occur on a particular date in the fall. It is a pulse event, occuring entirely on the given date, rather than over a period of time.

4.3.1.5 Tree Processes

The currency is cover of trees. The units are square meters per square meter. Only four kinds of flows are involved, as diagrammed in Fig. 3.2:

1) growth of cover
2) loss of cover
3) harvest loss
4) fire loss

Growth of cover. Cover growth is based on site quality, current site fertility, and current cover. The maximum cover attainable by a species on an ERU ($I_{(5,1)}$) is a user input value. This maximum is adjusted by the current site fertility ($I_{(3,5)}$). The growth ra is a modified logistic in te which the asymptote is the product of maximum cover and fertility:

$$F_{(5,1)} = X_{(5,1)} \cdot P_{(5,1)} \cdot (I_{(3,5)} \cdot I_{(5,1)} - X_{(5,1)}) \div (I_{(3,5)} \cdot I_{(5,1)})$$

The growth rate parameter ($P_{(5,3)}$) was calculated by hand to match qualitative literature discussions of growth rates of pinyon and juniper.

Cover-weight relationships for pinyon and juniper were obtained from Meeuwig et al. (1979). Meeuwig showed that this relationship is nearly independent of crown size or tree age. Since tree cover is the state variable, leaf area index and leaf biomass are obtained as intermediate variables based on aerial cover from data in Meeuwig et al. (1979).

Loss of Cover. Cover loss represents natural mortality.

Harvest and Fire Loss. Harvest loss and fire loss are functions of the intensity of harvest and fire events respectively.

Litter fall rates for trees are based on an assumed 3 year life span for needles of pinyon and juniper. The daily turnover rate is then:

$$P_{(5,6)} = 1.0 \div (3 \cdot 365)$$

4.3.1.6 Herbaceous and Shrub Processes

The currency is grams dry weight of biomass per plant for shrubs and grams dry weight per square meter for herbaceous species. As shown in Fig. 3.2, the following processes are considered:

1) photosynthesis
2) respiration
3) translocation
4) death of plant parts
5) grazing

Plant biomass arises through photosynthesis into a storage organ of the plant. There translocation carries biomass into roots or shoots. Death and respiration are possible for all root and shoot components. Fire loss may claim shoots or standing dead, and shattering may also remove standing dead. The shattering and death losses lead to an increase of litter.

Photosynthesis. Daytime net photosynthesis is calculated as a function of leaf area, site fertility, availability of soil water, mean temperature, and hours of daylight (Fig. 4.13-4.14). Leaf area is an intermediate variable, derived from biomass. Available water refers to the soil layer with the least limiting soil water potential. The photosynthesis equation is based on the concept of optimal conditions for photosynthesis. At temperatures other than the optimum, photosynthesis is reduced. Also, soil water potentials less than zero reduce photosynthesis.

Figure 4.13 illustrates the shape of the photosynthesis response. The outermost curve represents non-limiting soil water while the inner curves show greater water stress. Notice that changing soil water potential alters the optimum and maximum temperature and the total amplitude of the response. The equations governing photosynthesis are adapted from Detling and Parton (1978). All variables for this function are calculated using abiotic variables for

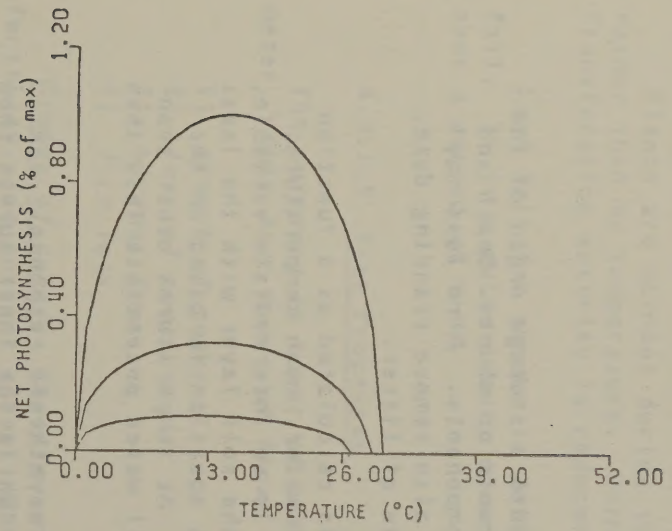

Figure 4.13. Photosynthesis as a function of soil water and temperature. Upper curve is for non-limiting soil water. Lower curves are for increasing water stress.

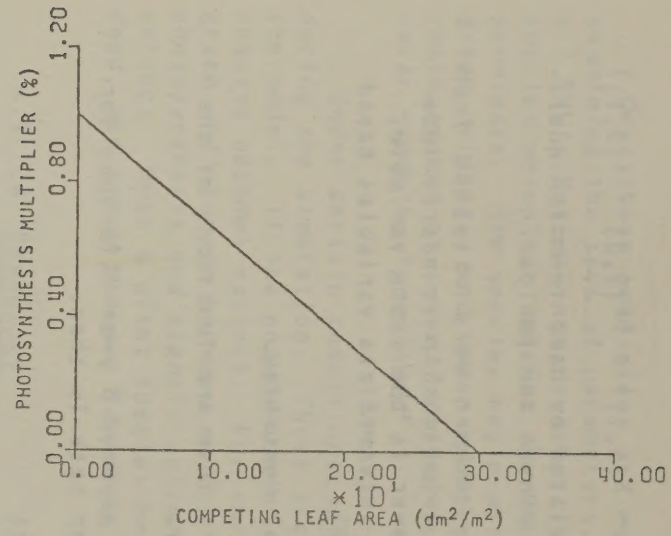

Figure 4.14. Effect of competing leaf area on net daily photosynthesis.

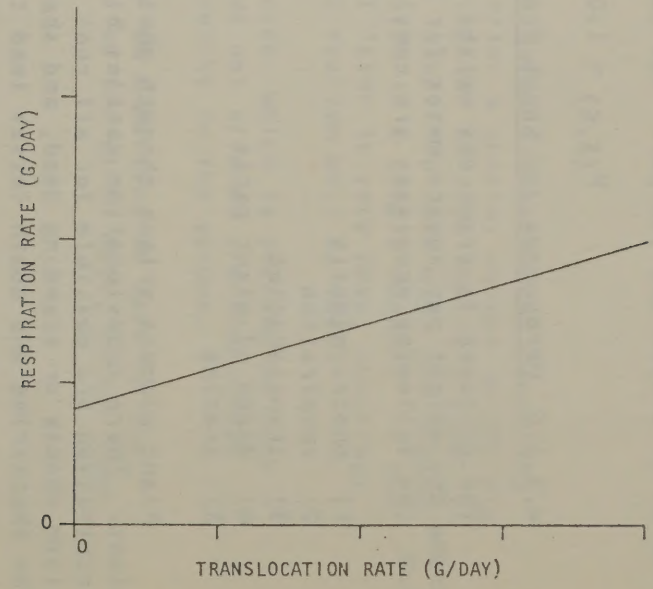

Figure 4.15. Daily respiration as a function of translocation rate.

active days. The parameters $P_{(3,4)}$, $P_{(3,5)}$, and $P_{(3,6)}$ were determined in such a way that the equation they are used in became very small at the wilting point.

The effect of soil water on maximum rate of photosynthesis is calculated as a decreasing exponential truncated at the wilting point:

$$I_{(3,2)} = \exp(P_{(3,4)} \cdot I_{(3,10)}); \quad \text{if } I_{(3,10)} > P_{(3,24)}$$

$$= 0; \quad \text{if } I_{(3,10)} \leq P_{(3,24)}$$

where $P_{(3,4)}$ is based on the assumption that at the wilting point, stomates are 90% closed:

$$P_{(3,4)} = \ln(0.1) \div P_{(3,24)}$$

The maximum temperature at which photosynthesis occurs at field capacity is decreased as available water becomes more limiting:

$$I_{(3,6)} = P_{(3,15)} + P_{(3,5)} \cdot I_{(3,10)}$$

The optimal temperature for photosynthesis follows the same type of relationship:

$$I_{(3,7)} = P_{(3,16)} + P_{(3,6)} \cdot I_{(3,10)}$$

An intermediate variable is then computed:

$$I_{(3,4)} = I_{(3,2)} \cdot \left[\left(\frac{I_{(3,6)} - I_{(3,21)}}{I_{(3,6)} - I_{(3,7)}} \right) \left(\frac{I_{(3,21)} - P_{(3,14)}}{I_{(3,7)} - P_{(3,14)}} \right)^{\left(\frac{I_{(3,7)} - P_{(3,14)}}{I_{(3,6)} - I_{(3,7)}} \right)} \right]^{P_{(3,3)}}$$

The form of this equation is illustrated in Figure 4.13. Total photosynthesis per day is then calculated from the following equation which includes a reduction factor for the effects of competing shade.

$$F_{(3,1)} = I_{(3,4)} \cdot P_{(3,9)} \cdot I_{(3,1)} \cdot I_{(10,2)} \cdot (1 - P_{(2,21)} \cdot I_{(3,9)} \cdot I_{(3,18)})$$

$P_{(2,21)}$ is based on the assumption that $1.0 \div P_{(2,21)}$ produces complete shade (McCree and Troughton 1966) and zero net photosynthesis. Complete shade should never occur on sagebrush ranges. The fertility multiplier adjusts photosynthesis rates for all species to the same degree. It adjusts for actual site fertility which is not reflected by the soil characterizations in the model, and for the fact that plants do not photosynthesize at the maximum rate all day due to variations in light intensity and water potentials.

Translocation and Respiration. Barnes and Hole (1978) show that a model of translocation and respiration developed by Thornley (1977) can be adjusted

to a form which corresponds to the standard formulation of growth vs. maintenance respiration. In Thornley's model maintenance respiration results from energy required to maintain degradable components of the plant, largely proteins. Barnes and Hole restructure Thornley's model by doing some substitutions and get

$$R = \frac{(1-Y_G)}{Y_G}\frac{d(W-W_S)}{dt} + \frac{(1-Y_G)k_D W_D}{Y_G}$$

where the first term on the right is growth respiration and the second term is maintenance respiration (see Table for term definitions). They conclude that Thornley's model provides a sound theoretical basis for the concepts of growth and maintenance respiration. However, this formulation of Thornley's model is not satisfactory due to the presence of the derivative on the right hand side. A new derivation is thus required.

TERMS FROM THORNLEY (1977) AND BARNES AND HOLE (1978)

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k_D = Instantaneous rate of protein degradation

k_G = Instantaneous growth rate of plant structure

P_g = Gross photosynthesis rate

W = Total plant biomass, dry weight

W_D = Degradable portion of plant, mainly proteins

W_N = Nondegradable portion of plant, excluding nonstructural carbohydrates

W_S = Nonstructural carbohydrates (storage)

Y_G = Conversion efficiency of carbohydrates into structural components

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Beginning with Thornley's model

$$\frac{dW_S}{dt} = P_g - k_G W_S + k_D W_D$$

$$\frac{dW_D}{dt} = Y_D Y_G k_G W_S - k_D W_D$$

$$\frac{dW_N}{dt} = (1-Y_D)Y_G k_G W_S$$

$$R = (1-Y_G)k_G W_S$$

the reformulation is achieved by separating the term $k_G W_S$ into its component parts; translocation for new cells and that for maintenance. If we assume that degraded proteins must be repaired as a part of cell homeostasis, then, with k_G now representing only the growth of new cells, the third equation remains the same and we get

$$\frac{dW_S}{dt} = P_g - k_G W_S - \frac{k_D W_D}{Y_G} + k_D W_D$$

$$\frac{dW_D}{dt} = Y_D Y_G k_G W_S - k_D W_D + \frac{Y_G k_D W_D}{Y_G}$$

$$R = (1-Y_G)k_G W_S + \frac{(1-Y_G)k_D W_D}{Y_G}$$

Canceling terms yields

$$\frac{dW_S}{dt} = P_g - k_G W_S - \frac{(1-Y_G)k_D W_D}{Y_G}$$

$$\frac{dW_D}{dt} = Y_D Y_G k_G W_S$$

$$R = (1-Y_G)k_G W_S + \frac{(1-Y_G)k_D W_D}{Y_G}$$

where the last term on the right in the first equation is loss from storage directly to respiration. Thus, reformulated, only the growth respiration fraction of total respiration is altered from Thornley's model.

A further assumption can be made that protein content is not highly variable and so can be approximated by a constant (seasonally varying) percentage of the part of the plant in question.

If we let k_{pi} be the protein content of plant part i, k_{Gi} be the rate of translocation to plant part i, and subscript the W terms with i, the entire model now becomes

$$\frac{dW_S}{dt} = P_g - \sum_i k_{Gi} W_S - \sum_i \frac{(1-Y_G)k_D k_{pi} W_i}{Y_G}$$

$$\frac{dW_i}{dt} = Y_G k_{Gi} W_S \quad \text{for all } i$$

$$R = \sum_i (1-Y_G) k_{Gi} W_S + \sum_i \frac{(1-Y_G) k_D k_{pi} W_i}{Y_G}$$

Some additional considerations involve interpreting Y_G and k_D from Thornley (1977) in terms of the rest of the model used in this report. Because net photosynthesis is estimated, rather than gross, all respiration terms for green biomass are only calculated for the night hours unless photosynthesis is zero in which case maintenance respiration is calculated for 24 hours.

It is logical to assume that the protein degradation rate (k_D or $P_{(3,7)}$) varies as a function of temperature and water, at least. However, no model for these relationships could be located which is compatible with the overall model as formulated. Therefore, an initial estimate was made using the values for barley and maize in Barnes and Hole (1978). Since their data were for nearly optimal growing conditions, the values obtained should be near the maximum year long values. Adjustments were made accordingly.

Conversion efficiency of carbohydrates into structural biomass ($P_{(3,25)}$) is given by de Vries (1972) as ranging from .7 to .75 which is well within the theoretical limits discussed by Barnes and Hole (1978).

The protein contents of plant parts (k_{pi}) were estimated by season. Total protein content values in the literature were separated into structural and metabolic fractions (McGill *et al.* 1981).

	per cent of Nitrogen	
	structural	metabolic
roots	46	54
shoots	35	65

The metabolic fraction times the total plant protein gave the per cent metabolic protein ($P_{(3,28)}$, $P_{(3,29)}$, $P_{(4,8)}$). Seasonal data was used where available. Stem percentages were assumed to be the same as for roots. Because of the large amount of nonliving wood in older shrubs, root and woody protein contents were reduced by a factor of 0.10 for the larger size class of shrubs.

The respiration equation may then be translated into standard notation as

$$F_{(3,4)} = 0$$

$$F_{(3,5)} = [((1-P_{(3,25)}) \div P_{(3,25)}) \cdot P_{(3,7)} \cdot P_{(3,29)p} \cdot X_{(3,2)} + (1-P_{(3,25)}) \cdot F_{(3,2)}] \cdot (Z_{(C,8)} \div 24.0) \cdot dt$$

$$F_{(3,6)} = [((1-P_{(3,25)}) \div P_{(3,25)}) \cdot P_{(3,7)} \cdot P_{(3,28)p} \cdot X_{(3,3)} + (1-P_{(3,25)}) \cdot F_{(3,3)}] \cdot dt$$

$$F_{(4,13)} = [((1-P_{(3,25)}) - P_{(3,25)}) \cdot P_{(3,7)} \cdot P_{(4,8)p} \cdot X_{(4,4)} + (1-P_{(3,25)}) \cdot F_{(4,12)}] \cdot dt$$

The calculation of translocation is a little more complex. First, photosynthesis and basal respiration for the current timestep are added to storage. Then translocation is computed if storage biomass is larger than $P_{(3,13)} \cdot I_{(3,12)}$ and subtracted from storage. Thus, storage is updated twice, reflecting the fact that growth occurs only if there are surplus carbohydrates.

Translocation to structural parts of the plant from the storage organs depends upon the amount of material stored, availability of water, and root biomass. Because all photosynthate passes through the storage compartment in the model before becoming structural materials, the allocation equations are particularly important in determining plant proportions and ability to respond to grazing. The first step involves the allocation of photosynthate to total structural growth (new shoots and roots). This equation is based on Thornley (1976) and allocates photosynthate based on the relative amounts of structural and storage biomasses. All factors which vary by activity level are calculated with $I_{(3,16)}$.

$$I_{(3,11)} = P_{(3,11)} \cdot I_{(3,12)} \cdot X_{(3,1)} \div (X_{(3,1)} + P_{(3,1)} \cdot I_{(3,12)})$$

This equation is essentially the Michaelis-Menton function for first order kinetics, and represents the rate of translocation as a function of the sink strength.

This total amount of translocate is reduced by limiting soil water (Fig. 4.17). It is assumed that leaf expansion is more limited than is photosynthesis by shortage of soil water (Detling and Parton 1978). Thus, under limiting soil water, photosynthate accumulates in the storage organs, affecting a recharge of materials used during spring growth.

$$I_{(3,3)} = 1.0 - I_{(3,10)} \div P_{(3,19)}$$

The amount translocated is also reduced by sub-optimal temperatures, which also affects fall recharge of storage (Fig. 4.16).

$$I_{(3,8)} = 1.0 - (A - I_{(3,19)}) \div (P_{(3,14)} + (P_{(3,16)} - P_{(3,14)}) \div 2)$$

Both of these reduction factors range from zero to one.

The final rate of translocation to structural biomass is then given by

$$I_{(3,11)} = I_{(3,11)} \cdot I_{(3,3)} \cdot I_{(3,8)} \cdot I_{(3,18)}$$

which is equivalent to the constant term $k_G W_s$ in Thornley (1977).

The maximum amount of translocate cannot be so large that storage is reduced below a set percentage of the entire plant biomass. This percentage is reduced in the spring to allow draw down of reserves.

The quantity to be translocated is then allocated to shoots and roots based on arbitrary relative priorities of growth. These priorities help keep plant part proportions within bounds.

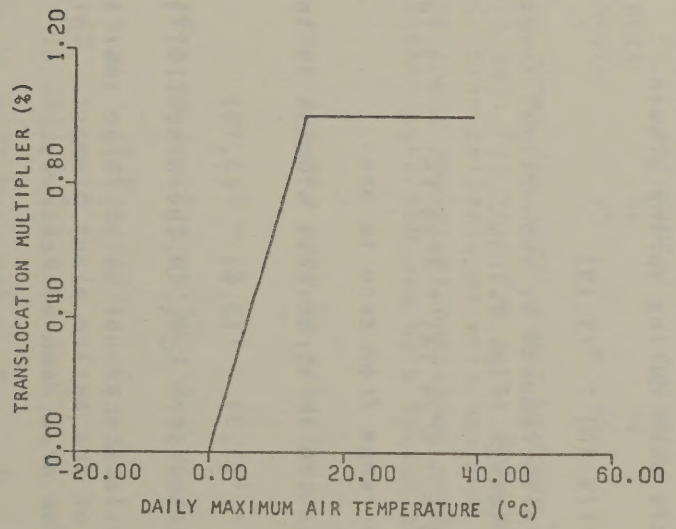


Figure 4.16. Effect of daily maximum air temperature on the rate of total translocation.

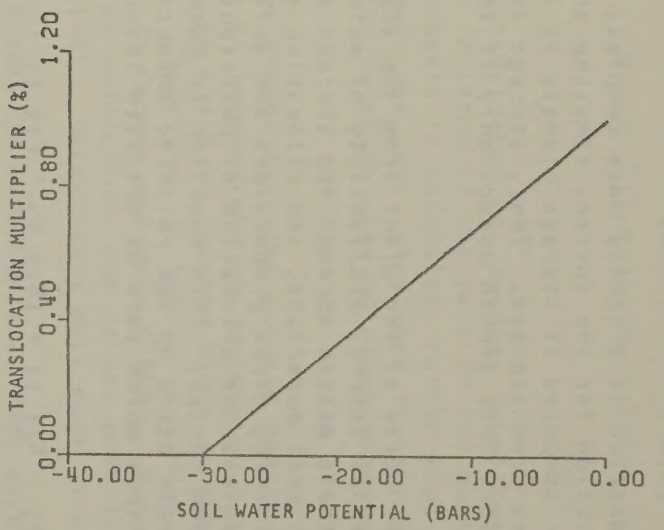


Figure 4.17. Effect of water potential for the wettest zone containing roots on the rate of total translocation.

Once a portion of the total to be translocated is allocated to the roots, this amount is divided between the roots in the soil layers based on the thickness of the layer and the water potential of the layer. Roots will not grow into a soil layer containing a hardpan or into any layer below one with a hardpan. A soil free of hardpans may be defined by setting the hardpan depth to any number larger than the depth of the C horizon.

Death of Plant Parts. Death of plant parts may occur due to senescence, adverse climate, carbohydrate deficit and perturbations.

Senescence occurs at a constant nominal death rate of plant part biomass, which reflects the average longevity of that part of the plant. The storage component is considered to be labile and, therefore, has no death rate. Only a small part of the total death of plant part biomass occurs through this process. In addition, during summer and autumn, curing causes transfer of green to standing dead at a constant rate. The curing parameter should be set to zero for high rates of grazing because very little leaf biomass will have time to cure before being eaten.

Drought and cold both cause death of plant parts. Drought causes death of green biomass in proportion to the severity and duration of drought below a critical moisture stress.

$$F_{(3,8)} = (P_{(3,10)} - I_{(3,24)}) \cdot P_{(3,2)} \cdot I_{(3,23)} \cdot X_{(3,3)}$$

Cold has a similar effect on death of green biomass:

$$F_{(3,8)} = (P_{(3,26)} - I_{(3,20)}) \cdot P_{(3,17)} \cdot X_{(3,3)} \cdot I_{(3,18)}$$

where $I_{(3,18)}$ and $I_{(3,20)}$ are based on $I_{(3,17)}$.

The effects of cold and drought are additive for green biomass. Woody portions are not affected by drought or cold. Roots are affected by drought in the same fashion as leaves, but not by temperature, since extreme temperatures are rare in the soil.

An important cause of die-back of plant parts in semiarid regions is shortage of carbohydrates. Arid zone perennial plants change size from year to year, often shrinking drastically in dry years. This ability to adjust the size of the organism is important in arid regions where rainfall varies greatly from year to year. Ignoring the homeostatic mechanism of adjusting the plant size in response to the carbohydrate energy status of the plant may explain the annoying tendency of plant models to "drift" over long periods of time. This homeostatic mechanism is implemented during the updating of state variables. If the respiration demand would draw carbohydrate reserves below a critical minimum, then twice the amount of shortage is taken from green, woody, and roots via increased death rates. Thus, the plant shrinks in proportion to an energy shortage, while at the same time, reserves are gradually used up, causing eventual death.

Perturbations such as fire, grazing, and herbicides directly remove plant parts and may kill the entire plant. These processes are discussed in other sections.

Grazing. Grazing of plant parts is the sum of grazing losses from all animal species. Grazing does not occur without also simulating the animal species dynamics. There is no grazing of belowground or storage components. The total grazing loss of green biomass, dead biomass and woody biomass for each plant species is calculated by the fauna submodel.

4.3.1.7 Shrub Population Processes

The currency is numbers of individuals per unit area. The flows as diagrammed in Fig. 3.2 are:

1) recruitment
2) mortality
3) fire loss

There are two size classes of shrubs: those greater than 15 cm high and those less than 15 cm high. The two size classes are used to distinguish between processes leading to shrub invasion and those allowing mature shrub persistence. Small shrubs must compete directly with grass and forbs for light and water due to their small size and shallow rooting depths. Larger shrubs have a height advantage over herbaceous species and can draw water from deep layers inaccessible to herbs. Thus, large shrubs may be in normal condition, while shrub seedlings are unable to become established.

Recruitment. Recruitment of small shrubs depends on the availability of water in the top soil layer, air temperature and the lack of competing vegetation (Fig. 4.18–4.20). These relationships are given by

$$I_{(4,1)} = P_{(4,2)} \cdot (1.0 - I_{(3,10)} \div P_{(3,24)}$$

$$I_{(4,2)} = \exp(P_{(4,3)} \cdot I_{(3,9)})$$

$$I_{(4,3)} = 1.0 - (P_{(3,16)} - I_{(3,21)}) \div (P_{(3,16)} - P_{(3,14)})$$

$$F_{(7,1)} = I_{(4,1)} \cdot I_{(4,2)} \cdot I_{(4,3)} \cdot dt$$

where dt indicates a time step.

Recruitment of large shrubs begins when small shrubs reach a threshold size. An arbitrary percent of the small shrubs graduate to the large class at each time step if the threshold size is passed.

Mortality. Because shrubs are quite long-lived relative to the length of model runs, large shrub natural mortality will usually be near zero. Small shrubs will suffer mortality from drought and competition. Mortality to both classes will occur due to herbicide application.

Fire Loss. Fire loss will affect both size classes. Sagebrush, for example, is fire-sensitive and almost all shrubs would be eliminated by a fire.

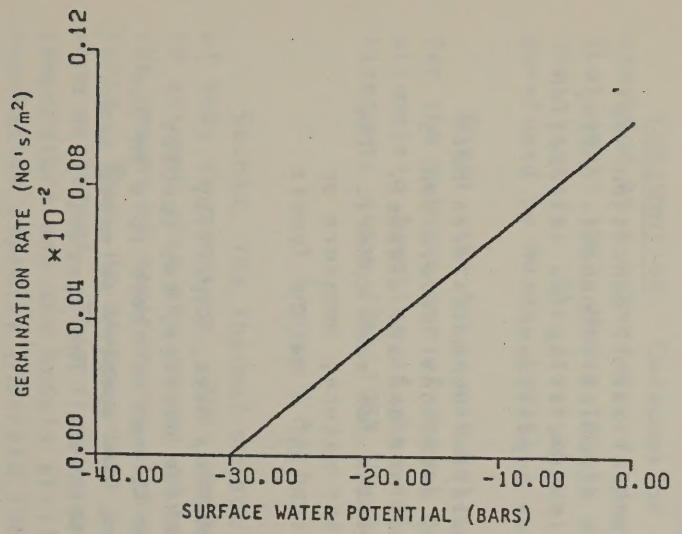


Figure 4.18. Nominal germination rate as a function of water potential in the top soil layer.

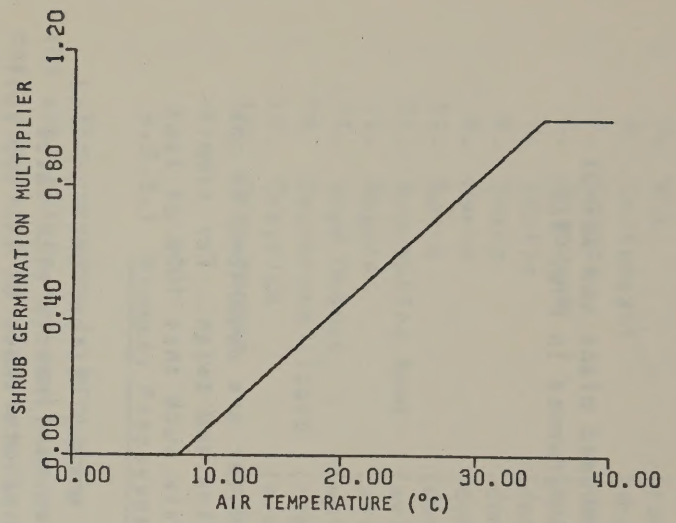


Figure 4.19. Effect of daily maximum air temperature on shrub germination.

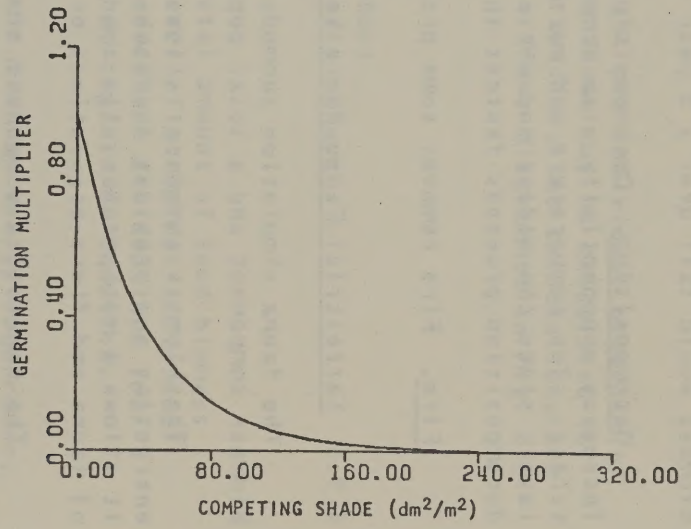


Figure 4.20. Shrub germination multiplier as a function of competing shade.

4.3.2 Litter Processes

The currency is grams per square meter of combined plant and animal litter. The different flows considered are, as diagrammed in Fig. 3.2:

1) input of herb shattering
2) input of shrub shattering
3) input of tree needle and twigs
4) input of feces
5) input of dead animals
6) decomposition
7) fire loss

Inputs. Inputs from plant compartments to litter are described in the previous sections, except for inputs of tree needles and twigs. For simplicity, tree litter fall is modeled as a constant rate such that 100% of leaf biomass would fall over a 3 year period.

Decomposition. Decomposition is computed as a respiration function that increases exponentially with temperature and decreases linearly with water stress. The temperature and moisture potential used are those of the top soil layer, since the oldest and wettest litter occurs at the soil surface and decomposition proceeds fastest there.

Fire. Fire removes some proportion of the litter when it occurs.

4.3.3 Terrestrial Fauna Processes

The fauna simulation submodel has two components, a "typical individual" biomass component and a total population component.

The biomass component allows simulation of general animal condition and energetics and provides feedback to the population dynamics component. Also, it allows a more mechanistic approach to be used in simulating the interaction of fauna and flora populations or predator and prey populations.

The population component simulates total population dynamics over both time and space. For the more "important" species, additional resolution is obtained by dividing the population into cohorts of sex and age classes. Likewise, additional typical individuals are simulated for each cohort. The possible chorts are combinations of female, male and mature, immature or juvenile age classes. The least resolution permitted is a mature female cohort.

The major animal classes represented are Mammalia, Aves, Reptilia, Amphibia, Pices, Crustacea, and Insecta. Within these classes, key species are selected for simulation based upon their value to man or their role in the ecosystem. Since not all species can be simulated, the species selected are considered to be characteristic of a grouping of species. The species currently considered for the simulation are:

1. Mule deer (ruminant)
2. Pronghorn (ruminant)

3.	Elk	(ruminant)
4.	Cottontail	(small herbivore)
5.	Coyote	(mammalian predator)
6.	Chipmunk	(rodent)
7.	Cattle	(domestic livestock)
8.	Sheep	(domestic livestock)
9.	Horse	(domestic & feral livestock)
10.	Burro	(domestic & feral livestock)
11.	Red-tailed hawk	(avian predator)
12.	Magpie	(avian omnivore)
13.	Sage Grouse	(upland game bird)
14.	Sagebrush lizard	(reptile)
15.	Crayfish	(crustacean)
16.	Grasshopper	(insect)

4.3.3.1 Biomass Processes

The currency is kilograms of live body weight per individual organism of the appropriate sex-age cohort. Several biomass flows may be calculated for each simulated species cohort. For many of the species, the calculations are identical except for changes in parameters. The flows diagrammed in Fig. 3.3 are:

1) Consumption by individuals of a cohort
2) Natality of youngest-cohort individual
3) Recruitment/maturation from younger cohort
4) Immigration/emigration by individuals of a cohort
5) Mortality of individuals of a cohort
6) Decomposition of dead animals

Consumption. Consumption represents the total amount of food biomass consumed by a cohort based upon the metabolic needs of a typical individual (Lasiewski 1967, McNab 1979). These metabolic needs are divided into four constituents. The first three are calculated from regression equations developed by Wunder (1975).

First, the basal metabolic need refers to the minimum energy requirement for the maintenance of normal body functions. This need is assumed to be an allometric function of the individual's weight and also depends upon its taxonomic class (Zar 1968, Kendeigh 1970) (Fig. 4.21).

$$I_{(8,1)} = P_{(8,1)} \cdot P_{(8,2)} \cdot [X_{(8,1)}]^{P_{(8,3)}}$$

Second, the thermal metabolic need is the energy required for maintenance of body temperature. This need is of minor importance to poikilotherms. It is assumed that the amount of energy needed for thermal regulation is equal to the amount of heat energy either lost or gained by the body due to conductance. Thus, it assumes that an equal amount of energy is required to cool or warm an animal. This flux is influenced by the difference between the ambient temperature and the body's critical temperature, which is influenced by its insulation capacity (Herreid 1967, McNab 1970, Wunder 1975, Kendeigh 1969) (Fig. 4.22-4.23)

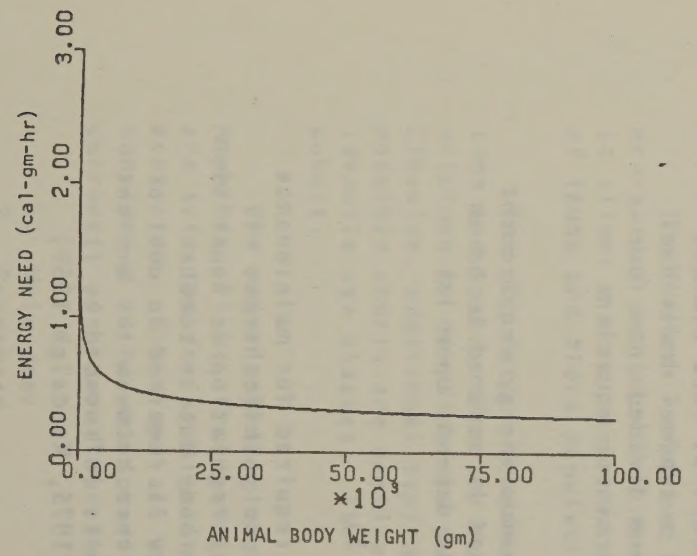


Figure 4.21. Basal metabolism energy requirement.

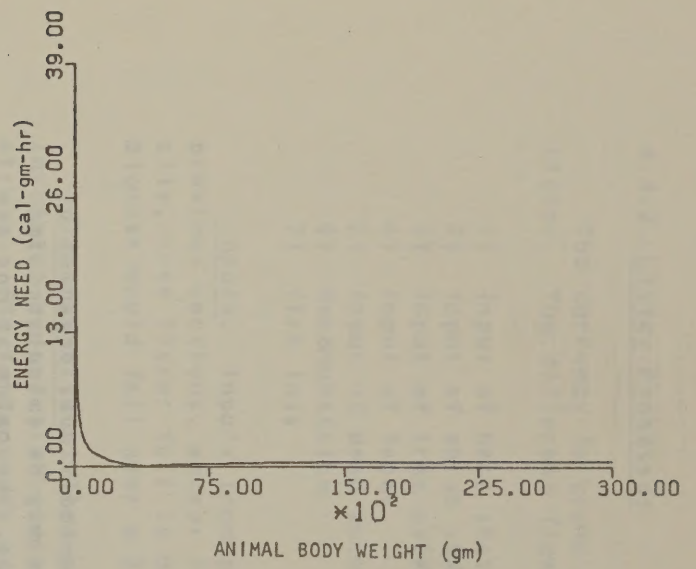


Figure 4.22. Thermal metabolism energy requirement.

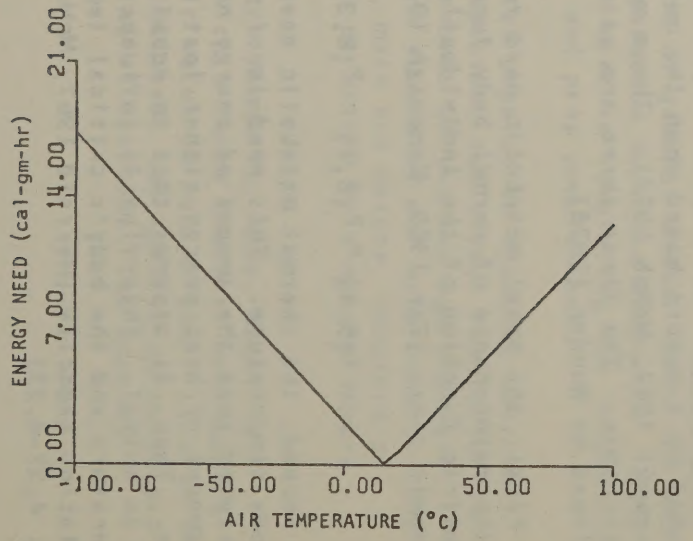


Figure 4.23. Thermal metabolism energy requirement.

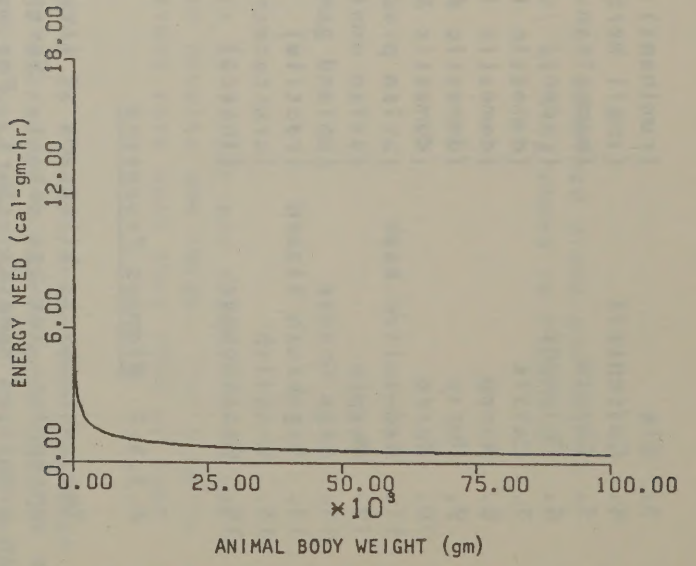


Figure 4.24. Activity metabolism energy requirement.

$$I_{(8,2)} = P_{(8,4)} \cdot [X_{(8,1)}]^{P_{(8,3)}}$$

$$I_{(8,3)} = P_{(8,16)} - P_{(8,6)} \cdot [X_{(8,1)}]^{P_{(8,7)}}$$

$$I_{(8,4)} = I_{(8,2)} \cdot \text{abs}\,(I_{(8,3)} - Z_{(C,3)})$$

Third, the metabolic need for activity and locomotion presently considers only movement in a horizontal plane at an average hourly velocity. Movement is based upon the animal's daily range and dispersal distance (Fig. 4.24).

$$I_{(8,6)} = P_{(9,7)} + I_{(8,5)}$$

$$I_{(8,7)} = I_{(8,6)} \cdot P_{(8,8)} \cdot [X_{(8,i)}]^{P_{(8,9)}}$$

Fourth, the metabolic need for an individual's body growth is based upon a Brody growth curve (Brody 1945, Humphreys 1979, Ricklefs 1967) (Fig. 4.25).

$$I_{(8,8)} = P_{(8,17)} \cdot (1.0 - \exp(P_{(8,17)} \cdot (I_{(9,1)} \div P_{(9,5)})))$$

The difference between the individual's expected weight and current body weight is converted to calories of energy. These calories are added to the three base metabolisms to determine total daily caloric requirements. Although an individual may attempt to obtain compensatory weight gain, the growth rate is still limited by the assimilation conversion efficiency (Milchunas et al. 1978).

$$I_{(8,9)} = (I_{(8,8)} - X_{(8,1)}) \div P_{(8,13)}$$

The total metabolic need is the sum of these four constituents.

$$I_{(8,10)} = I_{(8,1)} + I_{(8,4)} + I_{(8,7)} + I_{(8,9)}$$

It is assumed that an animal will always attempt to obtain enough energy for growth, although this attempt will not always be successful.

Foods are allocated on the basis of total demand and total availability (Watt 1968). Total demand is presently calculated from the amount of a food which would be needed to supply the total energy demand and its relative desirability or preference. A food's digestibility and caloric content are important in determining the amount needed to supply the energy demand.

$$I_{(8,11)} = P_{(8,20)} \cdot I_{(8,10)} \div (P_{(8,18)} \cdot P_{(8,19)})$$

Total availability has different meanings for the various food items which can be consumed. For woody flora species, availability includes green biomass and that portion of woody twigs which are palatable. For herbaceous species, it includes green biomass and a portion of standing dead. For fauna species, availability includes the biomass of all cohorts, but the younger cohorts are assumed to receive a much greater proportion of the predation.

For woody floral species:

$$I_{(8,12)} = (X_{(4,5)} + P_{(8,12)} \cdot X_{(4,4)}) \cdot X_{(7,q)}$$

where "q" indicates the size class of the shrub.

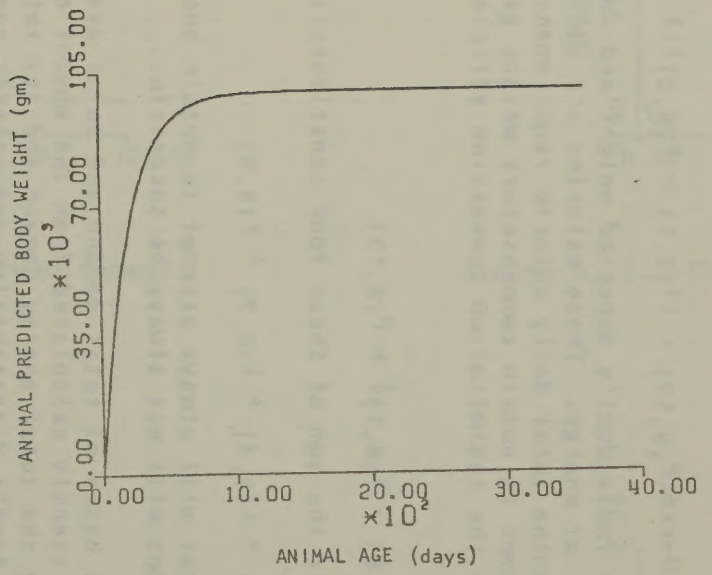


Figure 4.25. Animal growth rate (based upon a maximum weight of 100,000 gm and a life expectancy of 1,825 days).

For herbaceous floral species:

$$I_{(8,12)} = X_{(3,3)} + X_{(3,4)}$$

For fauna species:

$$I_{(8,12)} = X_{(8,1)} \cdot X_{(9,1)}$$

Availability is reduced by snow. If snow depth is greater than plant height then the maximum reduction occurs. This maximum is set at 50% because animals can dig and burrow to find forage covered by snow. Hibernating animals are not available as food.

Conversions are made to determine the total availability within the consumer's foraging or hunting range proportional to the acreage of the ERU Burge et al. 1973).

$$I_{(8,2)} = I_{(8,12)}; \quad \text{if } P_{(9,7)} \geq X_{(10,1)}$$

$$I_{(8,2)} = (P_{(9,7)} \div X_{(10,1)} \cdot dt \cdot I_{(8,12)}; \quad \text{if } P_{(9,7)} < X_{(10,1)}$$

If the available biomass of a species is less than the demand for it, then its relative abundance is reduced proportionally.

$$I_{(8,13)} = 1.0; \quad \text{if } I_{(8,12)} \geq \sum_{s=1}^{S} I_{(8,11)}$$

$$I_{(8,13)} = I_{(8,12)} \div \sum_{s=1}^{S} I_{(8,11)}; \quad \text{if } I_{(8,12)} < \sum_{s=1}^{S} I_{(8,11)}$$

where "s" indicates consumer species.

Relative scarcity reflects the likelihood of a consumer species finding the amount of forage or prey desired while competing with other consumer species for the same food, a limited resource (Fig. 4.26-4.28).

$$I_{(8,14)} = \exp(-I_{(8,11)} \div I_{(8,12)})$$

Thus, the amount of a forage or prey species allocated to a consumer species is a function of the amount desired, its relative abundance, and its relative scarcity.

$$I_{(8,15)} = I_{(8,11)} \cdot I_{(8,13)} \cdot I_{(8,14)}$$

It is assumed that the diet preference of the consumer species is constant over a season and does not change with forage or prey availability. Thus, when a desired species is not available, the consumer species will be forced to move to a different location rather than vary its diet. The value of the diet preference parameter must be determined prior to the simulation based upon the plant species chosen for simulation. Therefore, it more truly represents seasonal relative diet preference between simulated plant species.

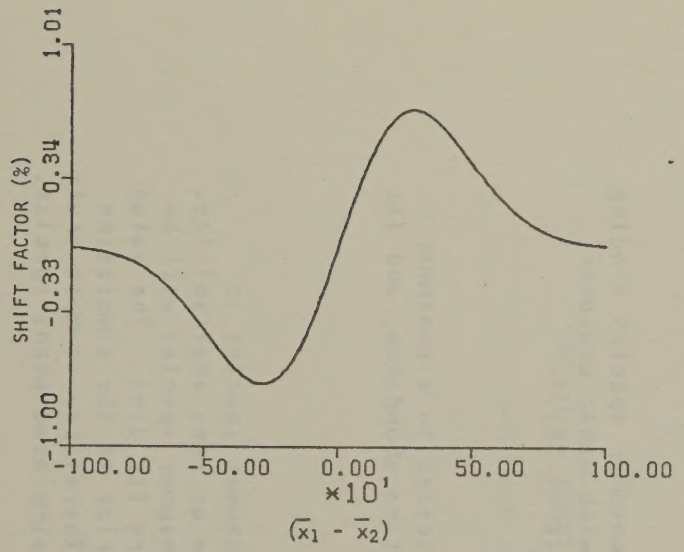


Figure 4.26. Population Proportion Shift.

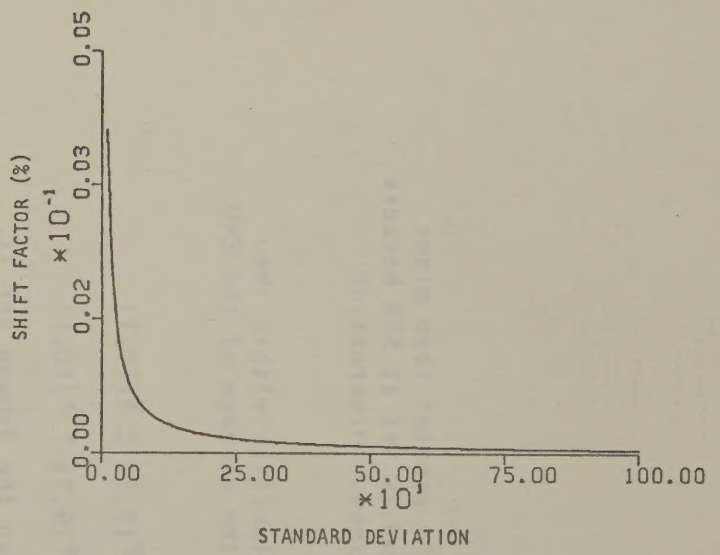


Figure 4.27 Population Proportion Shift (based upon a difference of 100 between the means).

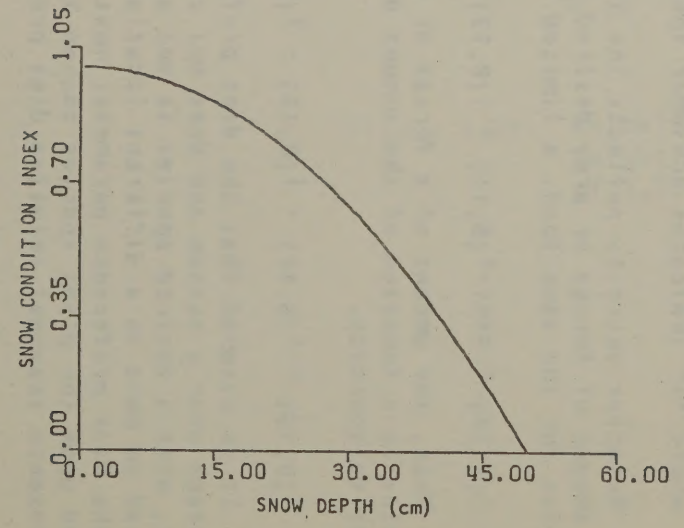


Figure 4.28. Habitat Condition Index for snow cover (based upon a critical depth of 50 cm).

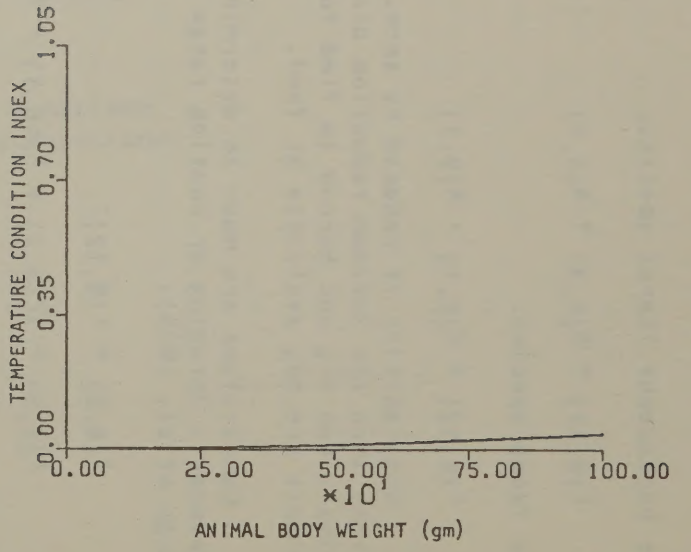


Figure 4.29. Habitat Condition Index for ambient temperature.

$$F_{(3,11)} = P_{(8,10)} \cdot \sum_{s=1}^{S} I_{(8,15)}$$

$$F_{(3,14)} = P_{(8,20)} \cdot \sum_{s=1}^{S} I_{(8,15)_s}$$

$$F_{(4,11)} = P_{(8,20)} \cdot \sum_{s=1}^{S} I_{(8,15)_s}$$

$$F_{(4,15)} = P_{(8,20)} \cdot \sum_{s=1}^{S} I_{(8,15)_s}$$

$$F_{(8,4)} = P_{(8,20)} \cdot \sum_{s=1}^{S} I_{(8,15)_s}$$

Assimilation, as used in the model, may apply to either anabolism or catabolism. As previously mentioned, an animal will attempt to consume enough food for growth. Any energy acquired above the amount needed for basal, thermal, and activity metabolisms will be used in anabolism. However, if insufficient energy is acquired, the animal catabolizes body tissue to offset the insufficiency. An animal is assumed to die if it has catabolized more than 30% of its maximum attained body tissue (Nagy et al. 1974).

$$I_{(8,16)} = \sum_{rs=1}^{RS} \left(I_{(8,15)_{rs}} \cdot P_{(8,18)} \cdot P_{(8,19)} \right) - I_{(8,9)_{rs}}$$

where "rs" indicates the food species consumed.

$$F_{(8,1)} = I_{(8,16)} \cdot P_{(8,13)} \cdot P_{(8,18)}; \qquad \text{if } I_{(8,16)} \geq 0.0$$

$$F_{(8,1)} = I_{(8,16)} \div P_{(8,14)} \cdot P_{(8,18)}; \qquad \text{if } I_{(8,16)} < 0.0$$

Natality, recruitment, immigration, emigration, and mortality. Within the context of individual biomass, these processes are basically accounting functions that are reflections of corresponding population processes. Shifts in the weight of the "typical" individual assume that the weights within the cohort population are normally distributed.

Decomposition. Decomposition of dead animals presently occurs at a similar rate to other litter decomposition. Decomposed carcass weights are added to the litter biomass.

4.3.3.2 Population Processes

The currency is number of individuals of a sex-age cohort for each fauna species. Like the biomass processes, population flows may be calculated for each species cohort simulated and many of the calculations are identical

except for changes in the cohort's parameters. As shown in Fig. 3.3, the processes are:

1) Natality of youngest cohort population
2) Recruitment/maturation of younger-cohort population
3) Immigration/emigration of cohort population
4) Mortality of cohort population

Natality. Natality is controlled by time. It is a function of the number of mature females in the population, their condition as indicated by body weight and species specific reproduction parameters. The sex ratio of newborns is assumed to be 1:1 (Tanner 1966).

$$F_{(9,1)} = 0.50 \cdot I_{(9,5)} \cdot P_{(9,3)} \cdot P_{(9,4)} \div (P_{(9,2)} - P_{(9,1)})$$

Natality is reduced linearly based on the mother's weight, becoming 0 at a weight corresponding to $(1-P_{(8,22)})$ times the mature female weight. The birth weight is a small percentage of the mature weight.

Recruitment/Maturation. Recruitment and/or maturation may be a function of time, weight or both depending upon the species. It is primarily an accounting function which moves a portion of the younger cohort into the next age class. This portion is calculated assuming a normal population age distribution (Figs. 4.26 and 4.27).

$$A = (I_{(9,1)n} - I_{(9,1)n-1}) \div (2.5071326 \cdot 0.1 \cdot I_{(9,1)n})$$

$$B = 0.5 \cdot (I_{(9,1)n} - I_{(9,1)n-1})$$

$$C = 2.0 \cdot 0.1 \cdot I_{(9,1)n}$$

$$D = A \cdot \exp(-B^2 \div C^2)$$

$$F_{(9,3)} = X_{(9,1)n-1} \cdot D; \quad \text{if } I_{(9,1)} \geq P_{(9,5)} \text{ or } X_{(8,n-1)} \geq P_{(8,7)}$$

$$I_{(9,1)} = I_{(9,1)} + dt; \quad \text{if } I_{(9,1)} < P_{(9,5)} \text{ or } X_{(8,n-1)} < P_{(8,7)}$$

Immigration/Emigration. Immigration and/or emigration comprise two distinct types of movement. The first involves movement between ERUs within a township (habitat selection). The second involves movement between ERUs and townships (seasonal migrations). This second type of movement has not yet been implemented in the computer code, but could follow an approach used by regional planners in predicting human population dispersion in relation to job locations, shopping centers, schools, etc. (Lee 1973).

There are three classes of mobility for a species: (1) limited, the species is not allowed to move from the ERU in which it resides, (2) local, the species may move among suitable ERUs within a township, and (3) regional, the species may move among suitable townships, in addition to its local movements. In addition, for classes (2) and (3) specific ERU's are defined into which movement is permitted. Thus, fences for livestock may result in cattle being restricted to 2 ERU's while other animals may move freely between all ERU's within a township. In addition, known behaviour of animals such as deer may be implemented. For example, if deer stay near the canyons and do

not venture to the center of a plateau, the center ERU's can be designated as off limits to deer.

Intra-township or "local" movement represents habitat selection by a mobile species. The selection is based upon a series of habitat rating indices (Walters et al. 1971, Whitaker et al. 1976). Currently, these indices reflect (1) snow conditions, (2) temperature conditions, (3) plant cover conditions, (4) food availability, and (5) previous population utilization. These indices are calculated in the same manner for all fauna species, however the importance of an index to a particular species may vary. Additional indices can be added to the determination.

(1) Snow Conditions (Gilbert et al. 1970)
(Fig. 4.28)

$I_{(9,6)} = 0;$ if $X_{(2,1)} > P_{(9,8)}$

$I_{(9,6)} = 1 - (X_{(2,1)} \div P_{(9,8)})^2;$ if $X_{(2,1)} \leq P_{(9,8)}$

(2) Temperature Conditions
(Figs. 4.29 and 4.30)

$I_{(9,7)} = \exp((Z_{(C,3)} - I_{(8,3)}) \div 3.0);$ if $I_{(C,1)} > I_{(8,3)}$

$I_{(9,7)} = \exp((2 \cdot P_{(8,16)} - I_{(8,3)} \div 3.0);$ if $I_{(C,1)} > (2 \cdot P_{(8,16)} - I_{(8,3)}$

$I_{(9,7)} = 1.0;$ if $I_{(C,1)} \leq I_{(8,3)}$ and

$I_{(C,1)} \leq (2 \cdot P_{(8,16)} - I_{(8,3)})$

(3) Plant Cover Conditions

$$I_{(9,8)} = \sum_{l=1}^{L} (I_{(3,13)_l} \cdot I_{(3,14)_l})$$

where "l" indicates plant class

(4) Food Availability

$$I_{(9,9)} = I_{(8,15)} \div I_{(8,11)}$$

(5) Previous Population Utilization

$$I_{(9,10)} = 2 \cdot (1 - (X_{(9,1)} / X_{(10,1)}) / \sum_{no=1}^{NO} X_{(9,1)} \sum_{ERU} X_{(10,1)}))$$

$I_{(9,10)} = 0;$ if $I_{(9,10)} < 0$

Note that all else being equal, animals should have a uniform density across the township.

The habitat rating of an ERU for an animal species is calculated as a weighted sum of the condition indices. The weights are the relative importance values (0-1) of the index to a particular species.

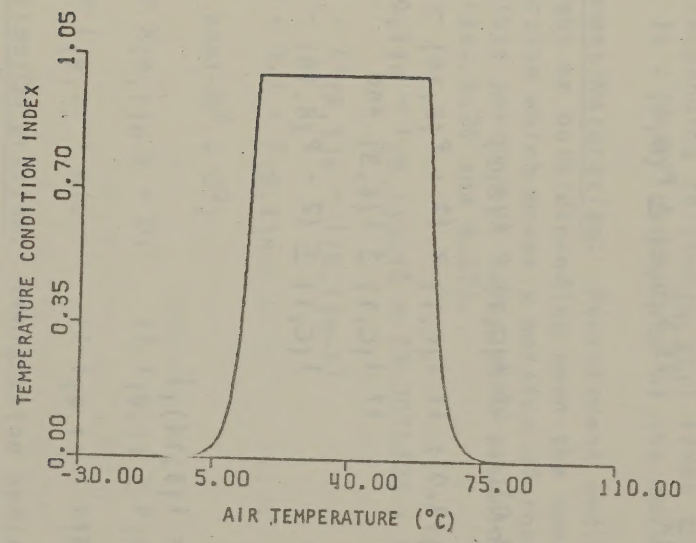


Figure 4.30. Habitat Condition Index for ambient temperature.

$$I_{(9,11)} = (P_{(9,9)} \cdot I_{(9,6)}) + (P_{(9,10)} \cdot I_{(9,7)}) + (P_{(9,11)} \cdot I_{(9,8)}) + (P_{(9,12)} \cdot I_{(9,9)}) + (P_{(9,13)} \cdot I_{(9,10)})$$

All ERUs within a township are considered to be adjacent to each other and accessible to mobile species. Thus, if an ERU (or habitat) can potentially be utilized by a species, then that ERU is evaluated for the species, even though the ERU may not be currently inhabited by the species. In this way, habitat colonization is permitted.

The township population is allocated among the ERUs proportionally to their relative ratings.

$$F_{(9,2)} = [(I_{(9,11)} \div \sum_{u=1}^{U} I_{(9,11)}) \cdot X_{(9,1)}] - X_{(9,1)}$$

where " " indicates specific ERUs.

Mortality. Mortality involves three types of mortality: natural mortality including starvation, predation mortality, and hunting or man-related mortality (Siler 1979).

Natural mortality also includes death from accidents and diseases. These causes are assumed to be fairly constant over time; however they may be augmented or diminished by the condition of the "typical" individual, as mentioned previously.

$$I_{(9,2)} = P_{(9,6)} \cdot X_{(9,1)}$$

Predation mortality is a result of the consumption processes. The younger age classes are assumed to receive larger predation losses than the older classes.

$$I_{(9,3)} = [P_{(9,4)_s} \cdot \sum_{s=1}^{S} I_{(8,15)_s}] - X_{(9,1)}$$

where "s" indicates the consumer species.

Hunting is implemented in the submodel as an event, since it is not viewed as a natural ecosystem function. It is a function of time, fauna population, human population or hunters, and other environmental factors such as snow cover and vegetation cover.

$$I_{(9,4)} = X_{(9,1)} \cdot (Z_{(M,3)} + Z_{(M,4)})$$

Thus, mortality is the sum of all these factors.

$$F_{(9,4)} = I_{(9,2)} + I_{(9,3)} + I_{(9,4)}$$

4.4 Resource Management

4.4.1 Discrete Events

Discrete time events generally represent one time management events, such as prescribed burning. Currently, the events which may be selected are:

1) Fire
2) Tree harvest
3) Herbicides
4) Fertilization
5) Revegetation
6) Stocking livestock
7) Livestock removal
8) Herd movement
9) Wildlife hunting

Fire. Fire is a user-defined event. The user specifies that there will be a fire on a certain date and gives the percent burn in terms of an "intensity" parameter. If a fire is scheduled when snow is present or if there is less than 50 grams of total biomass per m^2 present, the fire is aborted and an informative message is printed. Litter and herbaceous aboveground live and dead biomass and tree cover are reduced by the intensity of the fire. An intensity of 1 eliminates all organic matter aboveground. Biomass per shrub is not reduced by the fire, but the number of shrubs present is reduced. It is assumed that all shrubs present are fire sensitive. Also, a fire increases the site fertility, based on the intensity of the fire.

Tree Harvest. Trees are harvested based on the percent of extant crown cover that is to be removed. Cover of all species is removed equally. Harvesting an ERU without trees has no effect. Harvesting is a perfectly clean operation having no affect on soils, vegetation, or animals.

Herbicides. Herbicide application is a user-defined event. The application is defined in terms of the percent of the shrub population that is killed. Shrubs not killed are unaffected by the spraying and retain pre-spray vigor. Leaf and woody portions of killed shrubs are transferred to litter. All shrub species are affected the same.

Fertilization. The fertility status has two components: base fertility and current fertility. The base fertility can be used to adjust model productivity levels to compensate for site quality differences not accounted for by soil texture and depth, slope, elevation, aspect, and precipitation. The current fertility reflects changes in the fertility of the site due to fire and fertilization of the site. Fire acts as a fertilizing event in proportion to the intensity of the fire. A user-input fertilization event is given in terms of the percent increase in fertility over the current fertility level. Because the fertility affects the photosynthesis rate, doubling the fertility causes a doubling of the growth rate which gives far more than double net primary production. The current fertility level gradually returns to the base level over a period of about three years.

Revegetation. When a site is to be revegetated, input data having the same format as Flora initial condition data is appended to the event input file. In addition, an event with standard form is defined which schedules when and where the revegetation is to occur. When the event is scheduled, all plants are eliminated from that ERU, storage space is returned to available memory, and the new vegetation data is read in. Animals are not affected.

Stocking Livestock. Stocking and removal of stock are user-defined events. The user specifies the specie, the numbers of each cohort and the weight of a typical individual of each cohort to be stocked. A specific ERU must also be given. The event occurs before simulation of fauna dynamics. Animals other than livestock may be added by this routine. Introduction of a new species may be simulated in this way.

Livestock Removal. Animals are removed in the same way. If fewer animals are found than it is desired to remove, all animals of that age-sex class are removed but no error message is written.

Herd Movement. Animals of any species may be moved between ERU's in any township. The user only specifies the species, the current location of the animals, and the destination. All animals are removed from the location and averaged into the population (if any) found at the destination.

Rotation or other grazing systems may be defined by a sequence of movement events. Attempting to move animals that are not present cancels the event and an error message is written.

It is also possible to use this event to schedule animal migrations. Because no animals can move between townships, if land units are defined in different townships then deer (or other animals) will not be able to return once they are moved. If it is desired that deer be able to move freely during most of the year but it is known that they avoid an ERU during a certain season (due to disturbance perhaps), then they can be moved to an adjacent ERU at each timestep during that season. This is not very efficient but does show the flexibility allowed by the model.

Hunting Wildlife. Hunting seasons are user-defined events. The user specifies the location, the opening day, the season length, the species hunted and the predicted success ratio and wounding loss. The total number of animals harvested during the season is divided evenly among the involved time steps. Like stocking, this event occurs before simulation of fauna dynamics.

4.4.2 Continuous Events

Continuous events are those management influenced factors that occur essentially continuously. These would include human disturbance. These factors are handled as pseudo-driving variables and are read in every time step rather than being handled by the event scheduler. Human disturbance is conceptualized as a habitat rating factor but is not yet implemented.

5. MODEL IMPLEMENTATION AND EVALUATION

5.1 Study Site Description and Model Set Up

The following description of the Garat allotment is taken largely from internal BLM reports.

The Garat district consists of 90,563 hectares of total land of which 94 percent is federal land, 5 percent is state land, and 1 percent is private land. Climatic data are taken from McDermott, Oregon and Grasmere, Idaho. These data suggest that the average annual precipitation is about 25 cm, average maximum temperature is 24°C, average minimum temperature -9°C, and average growing season 75 to 86 days per year. Precipitation generally occurs as spring rains in April and May, and as January snowfall. The allotment ranges from 1524 to 1676 meters above sea level. There are several large basins. Basins can be traversed by four-wheel drive vehicles except where the drainages break into the bordering canyons. Water flow is seasonal or intermittent and generally occurs in the spring. Several playas are located in the northwestern portion of the allotment. Few springs are known to exist and the main source of livestock water is from reservoirs constructed to impound surface runoff. There are some 80 stock reservoirs, most of which hold water season long.

Basin big sagebrush and Wyoming big sagebrush cover about 75 percent of the upland area and low sagebrush (Artemisia arbuscula variety nova) is intermixed with big sagebrush on the shallower soil and covers about 20 percent of the upland area. Nonvegetated sites make up the remainder. Bitterbrush is found along the Owyhee river and together with juniper found in the draws and canyons makes up the major remaining vegetation types. The main grasses are bluebunch wheatgrass, Idaho fescue, and Sandberg bluegrass. Giant wildrye, and needleandthread grass are also present. Forbs are predominantly annuals, such as phlox and blue lupine with scattered balsamroot.

Principal game species in the unit are antelope, bighorn sheep, mule deer, sagegrouse, chukar, partridge, mountain and valley quail, and various water fowl. A herd of 19 California bighorn sheep were introduced from British Columbia in 1963 and the population estimated in May 1968 was 85 head. These animals live in the canyons which are not used by cattle to any great extent. Domestic sheep are not allowed within three miles of the canyon rims. There are currently no domestic sheep in the area. It was estimated that 100 head of antelope ranged within the Garat allotment in 1968. Hunting is on a permit basis.

As many as 4,000 head of cattle have been licensed to make use of the allotment in March to October. The six large pastures in the allotment range from 14,580 to 20,655 hectares in size. These are probably too large for efficient range management. In recent years the Petan Company has been licensed to run 2,200 to 3,800 head of cattle. They are trailed into the area in February and herded in March while the ground is still frozen. Then they are fed hay, calved, and turned onto open range from March 15 to April 15.

Spring use is concentrated in the dry lakes area since the stock water there may run short later in the season. The rest of the area is grazed

season-long. This is not beneficial to vegetation and large portions of the area are subjected to overgrazing resulting in an accelerated downward trend over a large portion of the area. The mesa tops, ridges, and canyon rims get relatively less use and the cattle concentrate around the large water holes. During a site visit the authors observed that the rocky low hills were nearly ungrazed while the flatter land closer to a road showed grass grazed right down to the ground. As it was December, we could not ascertain when the grazing occurred. A range readiness study shows that March 16, the beginning of the grazing season, is three to four weeks too early to permit grazing. A 1966 range survey showed carrying capacity of 11,400 animal unit months on federal range in the allotment. The capacity in a normal year is judged to be between 15,000 to 20,000 animal unit months. The 1966 figure is based on a subnormal precipitation year. Potential production is estimated to be in excess of 35,000 animal unit months. This will require range improvement, periodic rest, and other treatments, including seeding and brush treatment to rehabilitate approximately 25 percent of the allotment. It is estimated that over a 5 year period the present grazing capacity could be increased by 10,000 animal unit months.

The Petan Company has a total of almost 58,000 animal unit months of grazing on federal range of which 33,000 is in the Garat allotment in Idaho and the remainder at various sites in Nevada. All of these are from spring through fall with most in spring and summer. Winter grazing must be on private land.

5.1.1 ERU Delimitation

The criteria for defining ERUs depends on the size of the study site and the degree of spatial heterogeneity. In the case of the Garat, the huge acreage dictated that no spatial unit could be considered of less that 1500 acres, except for the riparian habitat which is highly productive. Beginning with BLM data on range site acreages by condition class, aggregation was done for each pasture (Table 5.1). The arrows (Table 5.1) indicate which units were lumped together. In addition, pasture 3 was merged into 2, 8 into 6, and 9 into 7 because these pastures were too small for modelling. All riparian acreages were lumped together. Barren land (ant hills, slick spots), talus slopes, and rock outcrops, were not simulated. Such land would have to be simulated in a future version of the model if the aquatic model were implemented because water runs off or accumulates on such bare land.

Once ERUs were defined they were named sequentially, given elevations, and had acres converted to hectares (Table 5.2). Elevations represent topographic position in relation to precipitation and temperature gradients. On the Garat the only known gradient is one of increasing rainfall to the east and north. Either this gradient or water run-on can yield an ERU in the 12 to 16" precipitation zone range site. Such sites as these, which differ from the average 10 to 13" regime, are given elevations which differ from the average for the Garat based on the elevation adjustment equation (Section 4.1.2). This results in slightly higher rainfall on these sites. If they are modelled as receiving run-on then their elevations would be the same as for the 10 to 13" range site.

Table 5.1 Aggregation of spatial units to form ERUs. Spatial units are shown by range site and condition class before and after aggregation for each pasture. Smaller pastures (3,8,9) are lumped into adjacent pastures before aggregation. Figures are in acres. Arrows indicate which pastures were aggregated.

Pasture #1 Original

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		5220.5	12.6		1477.2			30.2		1277.9
FAIR		4259.7			1189.0			28.6		994.8
GOOD		484.9	←	34.5	207.9		242.4	3394.2	484.9	
BURN										

Pasture #1 Aggregated

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		5220.5								
FAIR		4272.3			2666.2					
GOOD		519.4			207.9					
BURN										

Pasture #2+3 Original

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		3889.1	←	56.5	3492.8			69.7		1510.5
FAIR		4011.1	←	308.9	4556.4		33.1	881.2	150.2	349.9
GOOD		685.8			211.7		164.0	2296.7	327.9	71.5
BURN										

Pasture #2+3 Aggregated

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR					8049.2					
FAIR		8265.6								
GOOD		685.8			211.7					
BURN										

Table 5.1 continued

Pasture #4 Original

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		23370.6 ←	564.2		3657.1			67.3		4498.0
FAIR		↑ 4529.1			↓ 1712.6			141.2	220.5	497.9
GOOD		2711.4			546.4		92.9	1443.6	212.1	28.9
BURN										

Pasture #4 Aggregated

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		28463.9								
FAIR					5369.7					
GOOD		2711.4			546.4					
BURN										

Pasture #5 Original

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		8316.6 ←	379.6 ←	201.1	6709.3			272.0		1052.9
FAIR		↓ 10205.6	←	95.9	8241.7			269.2	8.5	1365.1
GOOD		1725.2	←	11.3	1737.1		102.7	1378.7	190.3	185.2
BURN										

Pasture #5 Aggregated

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR					14951.0					
FAIR		19198.8								
GOOD		1736.5			1737.1					
BURN										

Table 5.1 continued

Pasture #6+8 Original

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR	4484.4	21825.0	428.0		96.4			27.9	74.8	4493.5
FAIR	576.6	3727.4						111.9	335.8	576.6
GOOD		304.6			94.5		94.5	1331.5	210.8	
BURN		100.6						5.6	16.8	

Pasture #6+8 Aggregated

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR	5061.0	22349.4								
FAIR		3727.4								
GOOD		405.2			94.5					
BURN										

Pasture #7+9 Original

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR	69.7	24139.3	862.8	779.7	2534.2				64.6	1300.2
FAIR		8377.6	241.4	68.0	1827.6	178.7		27.5	262.3	433.5
GOOD		2825.7	58.7		1089.3	2653.3		398.7	157.6	145.3
BURN		1740.6	72.8	39.9	139.8	10.0		19.9	29.8	

Pasture #7+9 Aggregated

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR		25851.5			2534.2					
FAIR		8687.0								
GOOD		4737.7			5898.7					
BURN										

Table 5.1 continued

Pasture - Good Condition summed over all pastures

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR										
FAIR										
GOOD		10796.0		8696.3						
BURN										

Pasture - Riparian aggregated over all pastures, condition classes

CONDITION CLASS	LOAMY 7-10	LOAMY 10-13	LOAMY BOTTOM 12-16	LOAMY UPLAND 12-16	SHALLOW CLAYPAN 12-16	CLAYEY 12-16	RIPARIAN	ROCK OUTCROP	TALUS	BARREN
POOR										
FAIR										
GOOD							729.6			
BURN										

Table 5.2 ERU descriptions for the Garat. Pasture 3 is merged into 2. Pasture 8 is merged into 6. Pasture 9 is merged into 7. Riparian includes riparian acreages from all pastures. Pastures "GOODCLAYPAN" and "GOODLOAMY" are sums of good condition acreages over all pastures. This reflects inaccessibility to livestock for areas which have remained in good condition, making their location within a pasture irrelevant unless more stock ponds are built. In all cases acres are BLM plus state land. Elevations are based on the elevation of Owyhee for modal sites (10-13" P.Z.), and are used solely to calculate lapse rates for driving variables.

	ERU NAME	RANGE SITE	CONDITION CLASS	HECTARES	ELEVATION
1.	Pasture 1A	Loamy 10-13	Fair	3346.4	5396.
2.	Pasture 1B	Shallow claypan 12-16	Poor	3258.8	5766.
3.	Pasture 2A	Loamy 10-13	Poor	1597.4	5396.
4.	Pasture 2B	Loamy 10-13	Fair	1346.2	5396.
5.	Pasture 2C	Shallow claypan 12-16	Poor	1414.1	5766.
6.	Pasture 2D	Shallow claypan 12-16	Fair	1844.7	5766.
7.	Pasture 4A	Loamy 10-13	Poor	11523.8	5396.
8.	Pasture 4B	Shallow claypan 12-16	Fair	2174.0	5766.
9.	Pasture 5A	Loamy 10-13	Fair	7772.8	5396.
10.	Pasture 5B	Shallow claypan 12-16	Poor	6053.0	5766.
11.	Pasture 6A	Loamy 7-10	Poor	2049.0	5026.
12.	Pasture 6B	Loamy 10-13	Poor	9048.3	5396.
13.	Pasture 6C	Loamy 10-13	Fair	1509.1	5396.
14.	Pasture 7A	Loamy 10-13	Poor	10466.2	5396.
15.	Pasture 7B	Loamy 10-13	Fair	3517.0	5396.
16.	Pasture 7C	Shallow claypan 12-16	Poor	1026.0	5766.
17.	Goodloamy	Loamy 10-13	Good	1237.5	5396.
18.	Goodclaypan	Shallow claypan 12-16	Good	1150.6	5766.
19.	Riparian	Loamy 12-16	Good	292.4	5766.

5.1.2 Initial Conditions

To run a numerical difference equation model requires an initial value for each of the system state variables. Initial condition values for system state variables are based on general reasoning, BLM supplied data, and a survey of literature information. In this case, the initial date is January 1963.

For each ERU soils are defined based on the range site soil descriptions supplied by Rob Roudabush of the BLM, Boise, Idaho, area office (Appendix I). A surface soil layer is defined which is thinner than the A1 horizon and acts as a heat exchange layer for radiation and a seedbed for germination in the model. Other layers are defined to match as closely as possible the horizons of the soil. No lumping of horizons was necessary for the Garat. For each layer the thickness and percent stones are taken directly from the soil descriptions. The soil texture classes require the following conversion:

BLM		Model
clay	=	clay
clay loam	=	sand clay
silty clay	=	clay silt
silty clay loam	=	clay silt
silt loam	=	clay silt
loam	=	sand clay
fine sandy loam	=	silt sand
sandy loam	=	silt sand
sand	=	sand

Topographic features were likewise assigned based on range site descriptions. The gradual slopes present on the Garat (3%) and the mixing of aspects due to aggregation meant that aspect could not be assigned. However, since solar radiation is not affected by aspect in the current version of the model, this is of no consequence and aspects were therefore defined as NE. Albedo was given a value typical of sagebrush lands for all ERUs due to lack of site specific data.

Due to a complete lack of data, soil temperature and soil water initial conditions were based on intuition and trial runs of the model. Because of strong feedback in the model, erroneous guesses are quickly corrected by the model. This is especially true if the model is started in mid-winter when plants are dormant. Initializing soil temperatures to near zero degrees C and soil water to somewhere near saturation provides a good enough initial guess. Then the model may be test run for 1 year with average climate and the final values at the end of the simulated year used as initial conditions for the actual production runs.

Vegetation composition for each ERU was derived from BLM descriptions of potential natural plant community composition and production. Potential composition was used rather than inventory data because these tables are based on range sites over an average set of years. Inventory data would require a great deal of work to achieve the proper degree of aggregation. Because of the dearth of pysiological and ecological studies of most of the species on the Garat, only major species groups could be used. Initial conditions were derived by aggregating species in grass, forb, and shrub classes (Table 5.3)

and then dividing average annual production in a median year (Table 5.3) among these three classes. This process gives peak production. For grasses and forbs, it is assumed that approximately 50% of the biomass is belowground biomass at that season. Storage biomass is based on 12.5% of root biomass in midwinter (estimated from many sources).

The process for shrubs begins with an estimate of shrub size. Jerry Taylor (BLM, Idaho) estimated Wyoming big sagebrush to average .762 m tall by .61 m wide and low sage to average .3 m tall by .23 m wide. Equation 3, tables 1 and 2 in Rittenhouse and Sneva (1977) were used to estimate green and woody biomass from these dimensions. Root biomass was assumed to equal woody. Storage biomass was assumed to be about 5% of the total (Dina and Klickoff 1973). Low sage bushes were assumed to be 20% denser than Wyoming big sage (Rittenhouse, personal communication). Current annual production figures (Table 5.3) include both leaves and twigs so to relate this to total green certain proportions are required. Al Winward (personal communication) estimated that in June, current growth is about 65% leaves and 35% stem and that these leaves make up about 90% of the total leaves on the plant. The total shrub production divided by current annual growth gives the number of shrubs per m^2. For example, taking data in Figure 5.3a, with $84g/m^2$, 35% shrubs, and 66.56g of leaves in June,

$$\text{shrubs}/m^2 = (.35 * 84) \div (66.56 * .9 \div .65)$$

$$= 0.319$$

However, shrub numbers obtained by this procedure were somewhat too high to give realistic results. The source of the error was not apparent. Model runs were thus made to discover densities of sagebrush that would allow survival of grasses and forbs within the context of the model. Densities between .1 and .2 were found to be adequate.

Major species of grazing animals were determined by conversations with BLM staff. The final ones chosen for modelling were cattle, bighorn sheep, mule deer, coyotes, jackrabbits, and small mammals. Antelope were excluded because the small number present frequently moves off the Garat. For mule deer, only the resident herd was modelled. The small mammal category includes the white-footed mouse, Great Basin pocket mouse, kangaroo rat, grasshopper mouse, and least chipmunk. Since these taken together eat largely arthropods and seeds, neither of which is in the model, their food is defined to be litter. Therefore, if arthropods or seeds are modelled, the litter category and small mammal diets must be redefined.

Estimates of initial population densities and animal weights were obtained from BLM staff. These estimates were for the Garat as a whole.

The estimates of mule deer and bighorn populations were cut in half because they use land across the canyon which is not on the Garat.

For jackrabbits, it was computed that given a summer 1980 density of .75/ha with about 20% of these alive in midwinter, the population is

$$.75/ha \cdot 0.20 \cdot 70627.3\ ha = 10594$$

Table 5.3a. Plant community composition for range site loamy 10-13". (BLM 1980).

Common Name	Symbol	% Composition by Weight (Air-dry)	Range in Production (Air-dry) lbs/ac	kg/ha
Grasses and Grasslike		45-55(52.5)	180-605	202-678
Bluebunch wheatgrass	AGSP	35-45	140-495	157-554
Sandberg bluegrass	POSA3	1-5	4-55	4-62
Indian ricegrass	ORHY	1-2	4-22	4-62
Thurber needlegrass	STTH2	1-5	4-55	4-62
Squirreltail	SIHY	1-5	4-55	4-62
Idaho fescue	FEID	0-5	0-55	0-62
Foxtail wheatgrass	AGSA2	1-2	4-22	4-25
Nevada bluegrass	PONE3	T-2	T-22	T-25
*Cheatgrass brome	BRTE	0-2	0-22	0-25
Sod wheatgrass	AGROP2	T-2	T-22	T-25
Other perennials	PPGG	1-2	4-22	4-25
Forbs		10-15 (12.5)	40-165	45-185
Arrowleaf balsamroot	BASA3	1-5	4-55	4-62
Hooker balsamroot	BAHO	0-2	0-22	0-25
Tapertip hawksbeard	CRAC2	1-3	4-36	4-40
Lupine	LUPIN	1-2	4-22	4-25
Longleaf phlox	PHLO2	1-3	4-36	4-40
Hoods phlox	PHHO	1-3	4-36	4-40
Milkvetch	ASTRAG	T-2	T-22	T-25
Pussytoes	ANTEN	T-1	T-11	T-12
Biscuitroot	LOMAT	T-1	T-11	T-12
Fleabane	ERIGE2	1-2	4-22	4-25
Aster	ASTER	1-2	4-22	4-25
Larkspur	DELPH	T-1	T-11	T-12
Other forbs		2-4	8-44	9-49
Shrubs		25-35 (35)	100-385	112-431
Wyoming big sagebrush	ARTRW	20-30	80-330	90-370
Tall green rabbitbrush	CHVI8	1-4	4-44	4-49
Dwarf green rabbitbrush	CHVIP2	1-4	4-44	4-49
Eriogonum	ERIOG	0-2	0-22	0-25
Other shrubs	PPSS	1-2	4-22	4-25

* Not a part of original climax vegetation, but may now have established an ecological niche in the potential community.

Total Average Annual Production (Air-dry):

	lbs/ac	kg/ha
Favorable years	1100	1232
Median years	750	840
Unfavorable years	400	448

Table 5.3b. Plant community composition for range site loamy 7-10". (BLM 1980).

Common Name	Symbol	% Composition by Weight (Air-dry)	Range in Production (Air-dry) lbs/ac	kg/ha
Grasses and Grasslike		35-45(40)	105-382	118-428
Sandberg bluegrass	POSA3	20-30	60-255	67-286
bottlebrush squirreltail	SIHY	5-10	15-85	17-95
Indian ricegrass	ORHY	1-3	3-25	3-28
Thurber needlegrass	STTH	1-3	3-25	3-28
bluebunch wheatgrass	AGSP	0-2	0-17	0-19
*cheatgrass	BRTE	1-3	3-25	3-28
Forbs		5-15(10)	15-127	17-142
longleaf phlox	PHLO	2-3	6-25	7-28
globemallow	SPHAE	2-3	6-25	7-28
daisy	ERIGE	1-2	3-17	3-19
desert parsley	LOMAT	1-2	3-17	3-19
tansy mustard	DESCUR	1-2	3-17	3-19
larkspur	DELPH	T-2	T-17	T-19
milkvetch	ASTRA	T-2	T-17	T-19
aster	ASTER	T-2	T-17	T-19
Shrubs		45-55(50)	135-467	151-523
Wyoming big sagebrush	ARTRW	30-40	90-340	101-381
spiny hopsage	GRSP	3-5	9-42	10-47
littleleaf horsebrush	TEGL	1-2	3-17	3-19
perennial shrubs	PPSS	1-2	3-17	3-19

* Not a part of original climax, but may now have established an ecological niche in the potential plant community.

Total Average Annual Production (Air-dry):

	lbs/ac	kg/ha
Favorable years	850	952
Median years	550	616
Unfavorable years	300	336

Table 5.3c. Plant community composition for range site shallow claypan 12-16". (BLM 1980).

Common Name	Symbol	% Composition by Weight (Air-dry)	Range in Production (Air-dry) lbs/ac	kg/ha
Grasses and Grasslike		40-60 (50)	140-570	157-638
bluebunch wheatgrass	AGSP	25-35	87-332	97-372
Idaho fescue	FEID	20-30	70-285	78-319
Sandberg bluegrass	POSA3	1-5	3-47	3-53
squirreltail	SIHY	1-2	3-19	3-21
Nevada bluegrass	PONE	T-2	T-19	T-21
Thurber needlegrass	STTH2	1-5	3-47	3-53
*cheatgrass brome	BRTE	T-1	T-9	T-10
other perennials	PPGG	T-2	T-19	T-21
Forbs		10-20 (15)	35-190	39-213
longleaf phlox	PHLO2	1-4	3-38	3-43
milkvetch	ASTRA	1-2	3-19	3-21
lupine	LUPIN	1-2	3-19	3-21
arrowleaf balsamroot	BASA3	1-2	3-19	3-21
Hookers balsamroot	BAHO	1-2	3-19	3-21
biscuitroot	LOMAT	T-1	T-9	T-10
Indian paintbrush	CASTI	T-1	T-9	T-10
fleabane	ERIGE	T-2	T-19	T-21
aster	ASTER	T-1	T-9	T-10
perennial forbs	PPFF	2-3	7-28	8-31
annual forbs	AAFF	1-3	3-28	3-31
Shrubs		15-35 (35)	52-332	58-372
low sagebrush	ARAR8	15-35	52-332	58-372
tall gray rabbitbrush	CHNA2	0-2	0-19	0-21
twisted leaf rabbitbrush	CHVIP	0-1	0-9	0-10
tall green rabbitbrush	CHVI8	0-1	0-9	0-10
eriogonum	ERIOG	0-1	0-9	0-10
antelope bitterbrush	PUTR2	0-1	0-9	0-10
other shrubs	PPSS	0-1	0-9	0-10

* Not a part of original climax vegetation, but may now have established an ecological niche in the potential plant community.

Total Average Annual Production (Air-dry):

	lbs/ac	kg/ha
Favorable years	950	1064
Median years	600	672
Unfavorable years	350	392

Table 5.3d. Plant community composition for range site semi-wet meadow (riparian). (BLM 1980).

Common Name	Symbol	% Composition by Weight (Air-dry)	Range in Production (Air-dry) lbs/ac	kg/ha
Grasses and Grasslike		75-85(80)	1125-2550	1260-2856
sedge	CAREX	15-30	225-900	252-1008
bluegrasses	POA	15-30	225-900	252-1008
sod wheatgrasses	AGROP	15-30	225-900	252-1008
rush	JUNCU	5-10	75-300	84-336
bentgrasses	AGROS	0-3	0-90	0-101
*common Timothy	PHPR3	0-5	0-150	0-168
*Kentucky bluegrass	POPR	0-5	0-150	0-168
prairie junegrass	KOCR	1-5	15-150	17-168
dropseed	SPORO	0-2	0-60	0-67
muhly	MUHLE	0-2	0-60	0-67
*little barley	HOPU	0-2	0-60	0-67
northern barley	HOBR2	0-5	0-150	0-168
basin wildrye	ELCI2	0-2	0-60	0-67
other perennials				
Forbs		10-20 (20)	150-600	168-672
Rocky Mt. iris	IRMI	1-5	15-150	17-168
cinquefoil	POTEN	1-5	15-150	17-168
groundsel	SENEC	1-3	15-90	17-101
common yarrow	ACMI2	2-5	30-150	34-168
common camas	CAQU2	1-3	15-90	17-101
clover	TRIFO	1-5	15-150	17-168
gentian	GENTI	1-2	15-60	17-67
erigeron	ERIGE2	1-2	15-60	17-67
dock	RUMEX	0-2	0-60	0-67
other perennials		1-5	15-150	17-168
Shrubs		0-5 (0)	0-150	0-168
willow	SALIX	0-5	0-150	0-168
other perennials		0-5	0-150	0-168

* Not a part of original climax vegetation, but may now have established an ecological niche in the potential plant community.

Total Average Annual Production (Air-dry):

	lbs/ac	kg/ha
Favorable years	3000	3360
Median years	2000	2240
Unfavorable years	1500	1680

This was cut in half because the model allows unrealistically high grazing rates by juveniles and immatures. The total was then split equally between male and female matures.

Small mammals were modelled as chipmunks because the parameters were already available. Small mammal populations of all species on the Garat were converted to chipmunk populations based on weight ratios. Using 1977 data, this gave 8.76/ha and using the same assumptions as before

$$8.76 \cdot 0.2 \cdot 70627.3 = 123720$$

The figure of 2000 cows grazed on the Garat given by the BLM was reduced to 1000 in the model because (1) all 2000 cows are not grazed all season on the Garat, and (2) the immatures and juveniles graze unrealistically large amounts due to a problem in the model (discussed later).

Mule deer and bighorn sheep are largely confined to the canyon and the canyon rim and were so restricted in the model.

5.1.3 Driving Variable Records

Data for temperature, wind, pan evaporation, and precipitaion were obtained from the U.S. Weather Service. Day length values are calculated according to procedures outlined in Sellars' book Physical Climatology. Solar radiation is calculated according to Capiel (1970).

Weather Service data does not come in a format suitable for use in the model. Neither the Twin Falls, Idaho, nor Owyhee, Nevada, data tapes were complete. The first 3 months of 1963, missing from Twin Falls, was supplied by the first 3 months of 1964 from Twin Falls. The data were converted as follows: Month and date converted to Julian date; temperature changed from degrees F to degrees C; precipitation changed from inches to centimeters; wind changed from miles per day to kilometers per day; and pan evaporation converted from inches to millimeters. Because pan evaporation data was not available from Owyhee, Twin Falls data was used in all simulations.

Driving variable records are described in two ways. Plots of the variables (Fig. 5.2) show general trends and variability of the data. Specific values of standard statistics such as the mean, maximum, and minimum are given for each driving variable on each ERU (Table 5.4). All driving variables can be adjusted for elevation except hours of daylight, incoming solar radiation, and wind. Only precipitation required altering for the Garat.

Solar shortwave radiation and day length follow a sinusoidal function. Solar radiation values are within acceptable ranges, showing that even with estimated wind and evaporation in the winter, the equations of Capiel (1970) seem to work well. The values in Fig. 5.2 may be compared to the data in Fig. 5.1.

Air temperature values show the usual seasonal patterns.

Table 5.4. Statistical summary for climatic driving variables used for simulations.

AN ECOSYSTEM SIMULATION OF PERTURBATIONS DRIVING-VARIABLE STATISTICS

	UNITS	MEAN	ZEROES	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
				VALUE	DAY	NO.	VALUE	DAY	NO.	
BASE CLIMATE FOR GRID 5,10										
1. DAYLIGHT	HR	12.000	0	15.900	164	90	8.100	347	90	2.755
2. SHORTWAVE	LY	415.379	0	928.800	3094	1	60.000	118	3	160.333
3. TEMPMAX	C	15.477	31	36.700	3497	1	-16.700	3631	1	10.694
4. TEMPMIN	C	1.796	110	21.100	1310	1	-28.300	3631	1	7.583
5. TEMPMEAN	C	8.637	35	27.500	1310	1	-22.500	3631	1	8.956
6. PRECIP	CM	0.073	2826	3.230	2058	1	0.000	1	2826	0.235
7. PEVAP	CM	0.477	0	1.549	503	1	0.025	131	6	0.284
8. WIND	KM	168.445	0	574.190	2665	1	9.680	3385	1	63.429

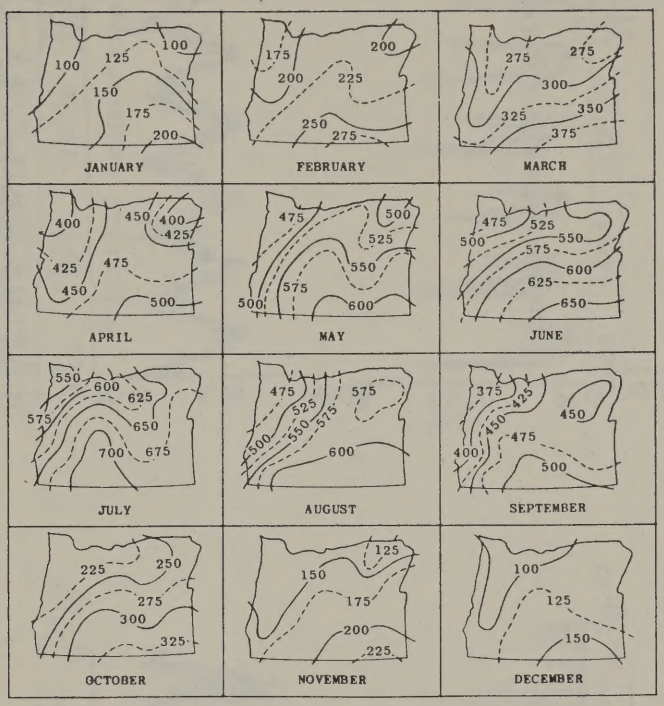
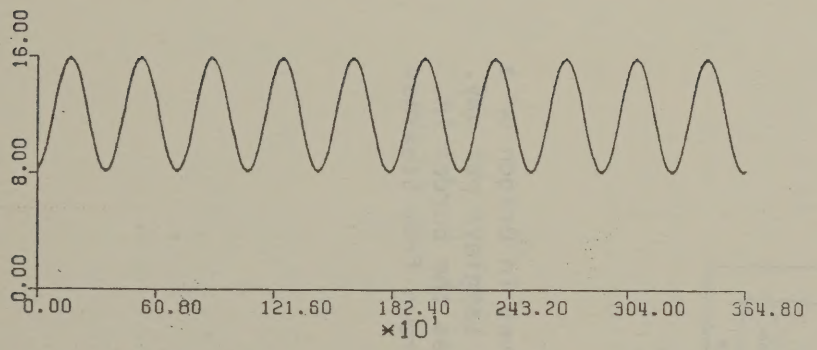
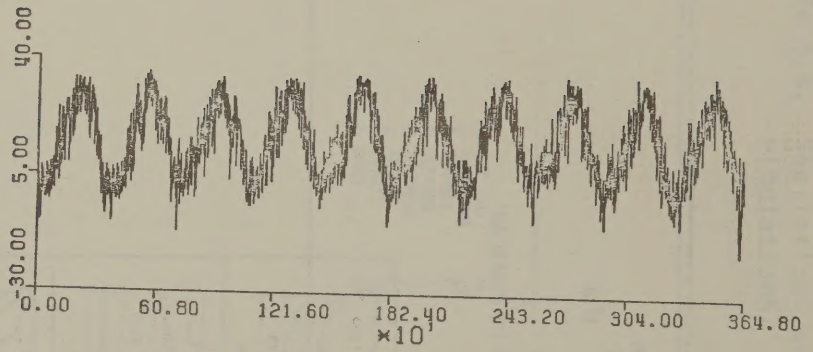


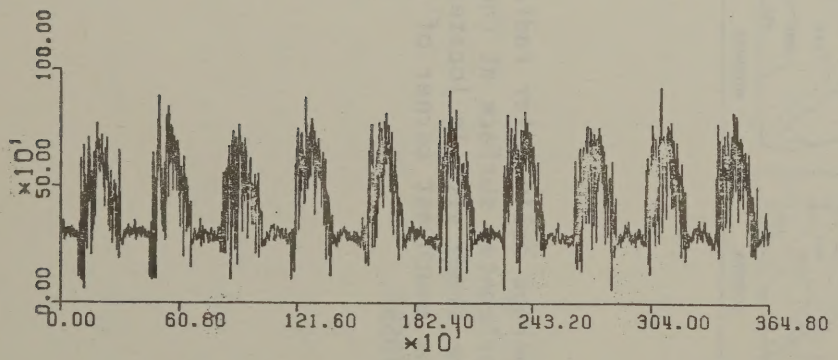
Figure 5.1. Average daily solar radiation received in Oregon on a horizontal surface at the ground in Langleys per day. The study site is located just across the border in the southwest corner of Idaho. Redrawn from Stearnes (1959).



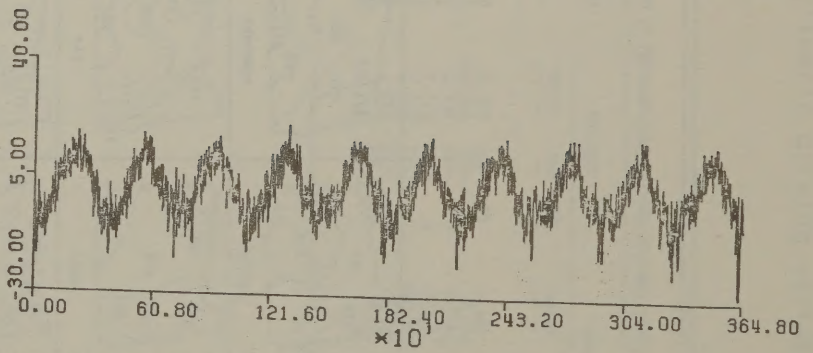
a. Daylight (hours)



c. Maximum daily air temperature (^{o}C).

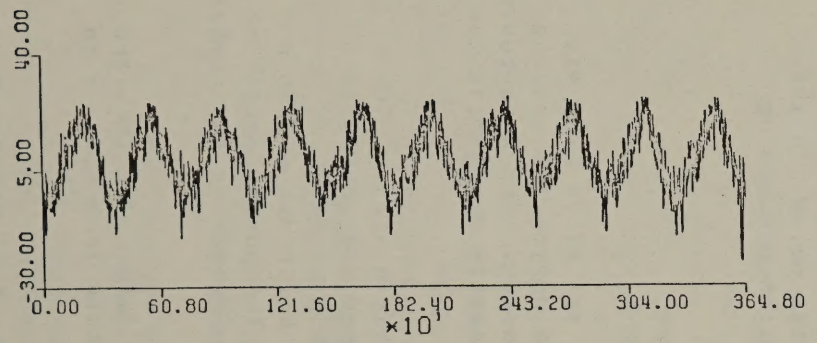


b. Shortwave radiation (langleys)

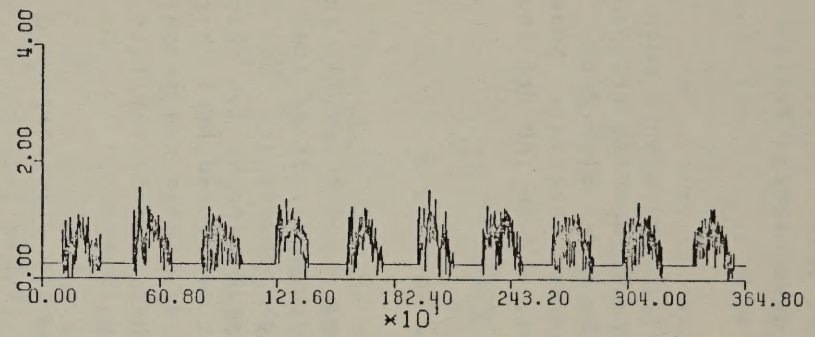


d. Minimum daily air temperature (^{o}C).

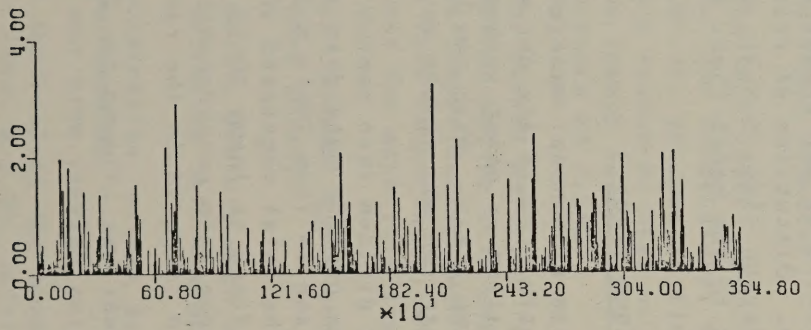
Figure 5.2. Climate variables results for the Garat, base climate 10-year run.



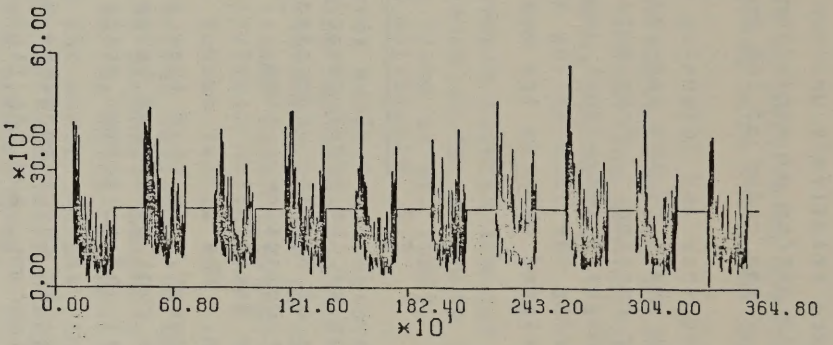
e. Mean daily air temperature (^{o}C).



g. Potential evapotranspiration (cm per day).



f. Precipitation (cm per day).



h. Wind (km per day).

Figure 5.2. (continued).

Wind velocities are relatively uniform throughout the year. However, there is a considerable degree of variation from day to day. Average daily winds were generally in the order of 168 km day^{-1}.

Precipitation frequency and intensity varied from year to year. The first few and last few years of the ten-year (1963 to 1972) record were much wetter than the middle portion. Precipitation events are frequently grouped on successive days. Highest individual inputs were of the order of 3.2 cm. Major inputs occur during the late spring through late summer interval. Snow and rain are differentiated only in the modelling process, not in the driving variable records.

5.2 Simulation Dynamics

Computer operation of the model described in Sections 3 and 4 results in many very large tables of numbers, representing the predicted values of the state variables and processes over time. These simulation results are then summarized by standard descriptive statistics and time series graphs for ease of user interpretation. The actual output tables are not presented here, but are available upon request. Instead they are summarized in tables and graphs which follow. For the runs described below the only output printed was file F (plant state variables) and J (animal state variables and flows).

There is a one-to-one correspondence between the summary statistics and graphs and the flow diagrams, and the flow-effect matrix (Table 3.2). However, for simplicity, only the most important processes and state variables have been printed. State variables are represented by continuous lines because the quantity exists through time. The process flows, on the other hand, are represented by bar graphs because the quantity exists at a discrete point in time. Discussion of results is presented below, in the section on model evaluation (Sec. 5.3.3), and in the section concerning suggested improvements to the model (Sec. 6.3).

5.2.1 Under Natural Conditions

For the simple case of nominal management, the full set of 19 ERUs was not necessary. Currently, cattle are not well controlled during the grazing season and no rest rotation or other system is being enforced. The area could thus be divided into two areas. With two ERUs and only cattle management to keep track of, a 10 year run was simple to set up.

The allotment was divided into canyon rim and main basin areas. The canyon rim was the area used by mule deer and bighorn sheep and consisted of ERUs 1, 3, 8, 17, 18, and 19 from Table 5.2, giving 9,798.3 hectares, approximately 14% of the total vegetated area. The main basin was 60,829.0 hectares. Both were defined as loamy 10-13 range sites. The poorer condition of cattle range was taken into consideration by slightly increasing the number of shrubs for the basin compared to the rim.

Hunting of mule deer was allowed for 27 days in the fall. One thousand head of cattle (cows plus calves) were run on the main basin from April 8 to September 30.

A last minute problem in the event routines (see Sec. 6.3) prevented use of any events, so cattle were not simulated and hunting was not done.

However, a file had already been set up describing events for a ten year, two ERU run and this file will be preserved with the other data files and the program listings.

All animals were entered on the canyon rim and at the first time step the model dispersed them between ERUs. Dispersion depends on the user defined list of ERUs, within which each species may occur.

Soil Temperature Submodel. Example results are not presented due to lack of space and time. Results were presented for a nearly identical version of the heat model in an earlier report (Jump et al. 1980).

In general, the soil temperatures exhibit a sinusoidal behavior which reflects a similar pattern of incoming radiation and air temperature. Soil temperature fluctuations are most pronounced in the surface layer and are damped in the deeper layers. Also, lower layer fluctuations occur later, or lag, those of the upper layers.

Shortwave radiation has the greatest influence on surface temperature, primarily due to the magnitude of the process. Longwave radiation may be both positive (representing energy gain by the soil) or negative (representing energy loss from the soil). During the winter months, the soil tends to gain energy from the air, while in summer, it reradiates energy to the night air. Vaporization energy is quite different between ERUs. This behavior results from the interaction of ambient air temperature and available soil water (Sec. 4.2.1), which varies with elevation and vegetal cover. The vaporization energy represents the energy required for vaporization of an amount of evaporation calculated by the soil moisture submodel.

The predicted temperatures of the soil layers seem fairly reasonable and are quite stable over a ten year run. The temperatures of the soil layers decrease with depth. The parent material, assumed to lie just below the lowest soil layer, functions as both a source of heat or a heat sink, dependent upon the temperature of the lowest layer. The parent material is assumed to maintain a constant temperature of 7.3°C.

Gain (or loss) of energy from the parent material is not very important compared to the other inputs. Conduction may be both positive (representing loss from the soil layer) or negative (representing gain by the soil layer). Conduction is strongly influenced by soil temperature, and thus, like soil temperature, exhibits a similar pattern for each soil layer.

Soil Moisture Submodel. The same comments apply about plots of soil moisture variables as for soil heat (see above).

In general, the soil moisture results exhibit much variation between ERUs. These differences are due to differing soil characteristics.

The only source of water is precipitation, either as rain or as snow, since runoff and runon are not yet implemented.

There are three major processes controlling the amount of precipitation which actually supplements soil water (Sec. 4.2.2), infiltration, evaporation

and runoff. Infiltration rates for a given amount of precipitation depend on loss to vegetation due to wetting and infiltration characteristics of the soil type. Evaporation, the counterpart to vaporization in the soil temperature submodel, is more strongly associated with ambient air temperature than available soil water. The greatest evaporation occurs on days with minimal rainfall due to the correlation between rainfall and low evaporation rates.

For this simulation, ground water functioned as an accumulator of all water percolating through the deep soil layer. It is important to note that some soil types and combinations may serve to contribute to ground water supplies, while other types do not.

The moisture of soil layer 1 is very closely related to infiltration rates. Also, a draw down of water levels in all layers occurs after the peak during snow melt, and is recharged during the fall.

Percolation may be both positive (representing loss from the soil layer) or negative (representing gain by the soil layer). Percolation rates are influenced by total water content, but are more closely related to volumetric water content. An important factor is the effect of the location of a claypan, which dramatically restricts water flow.

Transpiration loss to plants is an important soil water process, although the size of this loss is small compared to the size of the other processes. Since plant roots take up water from the soil layer with least resistance as measured by matric potential, the location (depth) of transpiration serves as an indicator of soil water conditions.

Floral Submodels. State variable time series graphs are shown in Figs. 5.3 and 5.4. Results of the example simulations are summarized in Tables 5.5 and 5.6. Plots and statistics are made for the two runs, one with and the other without animals, for comparison. Process rates were not plotted because computer costs for printing and plotting them were excessive. After suggested changes can be made (Sec. 6.3) it would be worthwhile to plot the flows for a detailed examination.

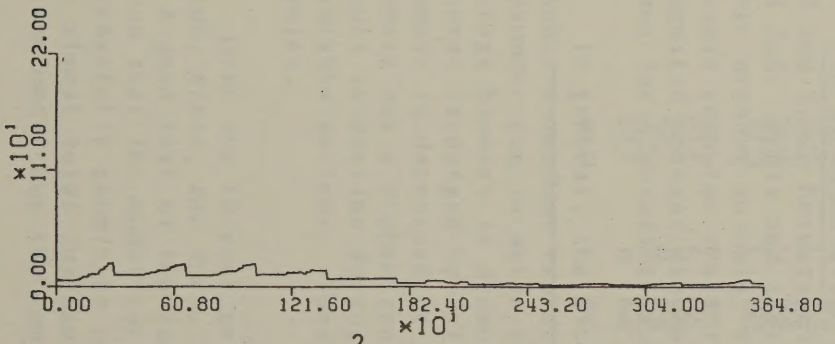
In general, the biomass dynamics are as follows. The green biomass reaches a maximum rapidly in the spring, levels off and then declines in the midsummer due to water shortage and exhibits some regrowth in the fall. Storage biomass is drawn down in the spring, fluctuates during the summer, becomes recharged by fall, and gradually declines during the winter. Net root biomass is decreased by nominal death, drought, and starvation. Because green biomass has a higher growth priority, root growth lags leaf growth. The net result is decline during winter and during drought and increase during favorable periods. These dynamics appear qualitatively reasonable for all species.

Over the 10 year period the proper dominance order is maintained of shrub, grass, and forb. Invasion of each into pure stands of the other would be a good test of the robustness of the competitive relationships. It was found that the model correctly predicted the failure of shrub seedlings to successfully germinate under conditions of intense competition (not shown). The almost total dominance of heavy stands of shrubs was predicted correctly by the model but the number of shrubs required for dominance was lower than

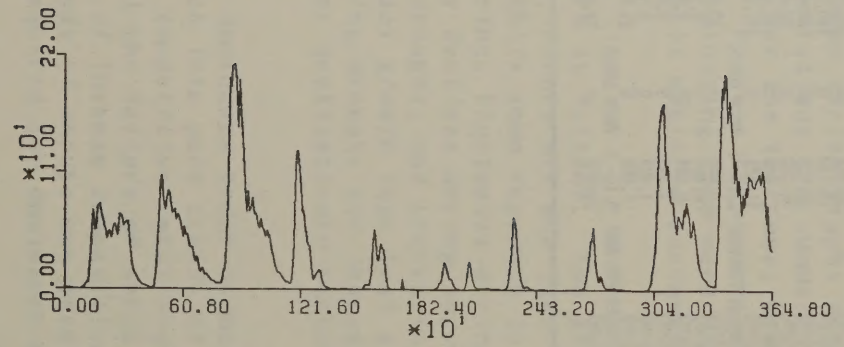
Table 5.5. Statistical summary of simulation results for plant state variables, without fauna.

AN ECOSYSTEM SIMULATION OF PERTURBATIONS PLANT-SUBMODEL STATISTICS

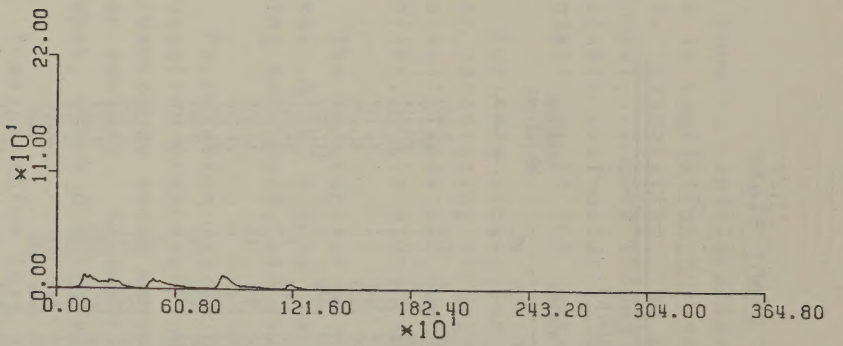
	UNITS	MEAN	ZEROES	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
				VALUE	DAY	NO.	VALUE	DAY	NO.	
SAGE . STATE VARIABLES FOR ERU		5,10- 1	CANYON RIM							
1. POPULATION	NO/M2	0.100	0	0.100	1	522	0.100	1	522	0.000
2. GREEN	G/M2	74.015	0	220.440	294	1	15.910	2891	1	53.170
3. STORAGE	G/M2	49.126	0	201.080	560	1	6.070	3017	1	37.416
4. SURROOT	G/M2	94.338	0	324.980	1050	1	0.150	2443	1	106.644
5. TOPROOT	G/M2	113.236	0	219.530	1638	1	38.200	3360	1	51.157
6. LOWROOT	G/M2	49.705	0	200.000	1	1	2.800	2268	1	41.175
7. DEEPROOT	G/M2	8.111	0	81.110	1	1	0.060	2639	8	14.027
8. NON-GREEN	G/M2	187.163	0	387.720	1050	1	57.560	3045	1	111.557
AGROPYRON. STATE VARIABLES FOR ERU		5,10- 1	CANYON RIM							
1. GREEN	G/M2	34.407	16	212.250	875	1	0.000	1708	16	45.993
2. STORAGE	G/M2	23.669	0	194.240	896	1	0.890	2660	1	23.216
3. SURROOT	G/M2	47.285	43	160.690	924	1	0.000	2394	43	48.852
4. TOPROOT	G/M2	41.578	0	105.700	903	1	6.990	2688	1	24.296
5. LOWROOT	G/M2	39.265	0	121.590	854	1	1.230	2296	1	31.185
6. DEEPROOT	G/M2	0.324	149	3.590	1	1	0.000	1652	149	0.588
7. NON-GREEN	G/M2	60.833	0	213.130	931	1	1.650	2723	1	54.465
FORBS . STATE VARIABLES FOR ERU		5,10- 1	CANYON RIM							
1. GREEN	G/M2	1.242	258	12.960	147	1	0.000	1400	258	2.558
2. STORAGE	G/M2	0.800	191	9.710	490	1	0.000	2289	191	1.202
3. SURROOT	G/M2	1.387	268	6.160	546	1	0.000	1750	268	1.965
4. TOPROOT	G/M2	1.547	150	6.200	322	1	0.000	2576	150	2.007
5. LOWROOT	G/M2	2.091	179	10.610	147	1	0.000	2366	179	2.773
6. DEEPROOT	G/M2	0.010	406	0.190	1	1	0.000	812	406	0.029
7. NON-GREEN	G/M2	2.132	140	10.140	343	1	0.000	2506	140	3.007
LITTER . STATE VARIABLES FOR ERU		5,10- 1	CANYON RIM							
1. LITTER	G/M2	22.491	0	59.980	1736	1	2.690	2639	1	13.267
SAGE . STATE VARIABLES FOR ERU		5,10- 1	MAIN BASIN							
1. POPULATION	NO/M2	0.130	0	0.130	1	522	0.130	1	522	0.000
2. GREEN	G/M2	68.185	0	184.400	644	1	19.280	3003	2	38.692
3. STORAGE	G/M2	43.611	0	227.500	1302	1	8.170	2646	1	26.919
4. SURROOT	G/M2	68.267	0	229.660	1050	1	0.240	2443	1	67.094
5. TOPROOT	G/M2	117.690	0	203.780	1309	1	43.440	84	1	42.008
6. LOWROOT	G/M2	49.493	0	200.000	1	1	4.410	2268	1	39.331
7. NON-GREEN	G/M2	174.193	0	311.580	1050	1	80.970	3045	1	72.678
AGROPYRON. STATE VARIABLES FOR ERU		5,10- 1	MAIN BASIN							
1. GREEN	G/M2	27.964	39	196.390	3409	1	0.000	1379	39	39.841
2. STORAGE	G/M2	19.132	0	140.320	3402	1	0.520	2653	1	18.952
3. SURROOT	G/M2	29.454	48	158.450	3486	1	0.000	2352	48	38.201
4. TOPROOT	G/M2	36.132	0	88.860	3598	1	5.270	2681	1	20.342
5. LOWROOT	G/M2	29.411	0	111.890	868	1	1.140	2303	1	28.655
6. NON-GREEN	G/M2	51.681	0	192.240	3493	1	1.190	2709	1	46.897
FORBS . STATE VARIABLES FOR ERU		5,10- 1	MAIN BASIN							
1. GREEN	G/M2	0.656	114	12.850	175	1	0.000	1358	114	1.687
2. STORAGE	G/M2	0.480	8	8.920	168	1	0.000	2653	8	0.790
3. SURROOT	G/M2	0.404	149	3.230	189	1	0.000	2030	149	0.572
4. TOPROOT	G/M2	1.042	0	5.290	175	1	0.020	2618	33	1.317
5. LOWROOT	G/M2	1.434	0	9.190	147	1	0.020	3010	5	2.012
6. NON-GREEN	G/M2	1.405	0	12.570	217	1	0.010	2660	21	2.262
LITTER . STATE VARIABLES FOR ERU		5,10- 1	MAIN BASIN							
1. LITTER	G/M2	20.407	0	74.880	1407	1	1.980	2639	1	12.404



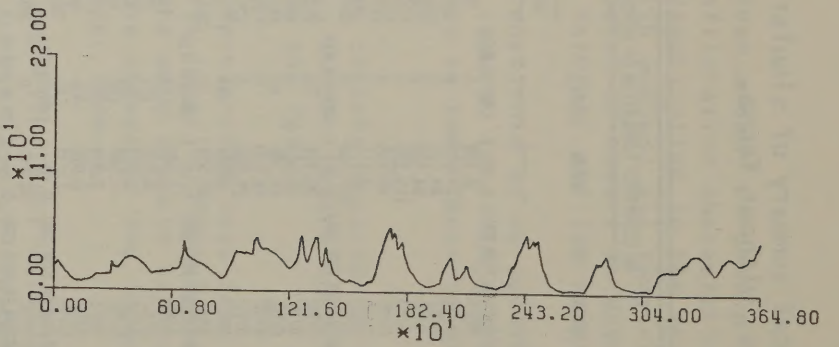
a. Sage green, g/m^2, on Canyon Rim.



b. Agropyron green, g/m^2, on Canyon Rim.

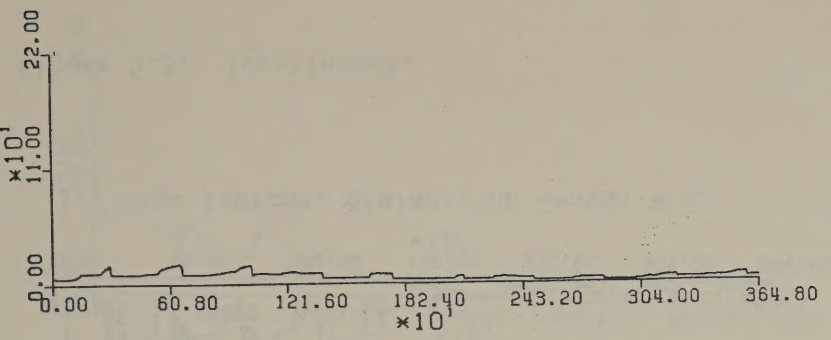


c. Forbs green, g/m^2, on Canyon Rim.

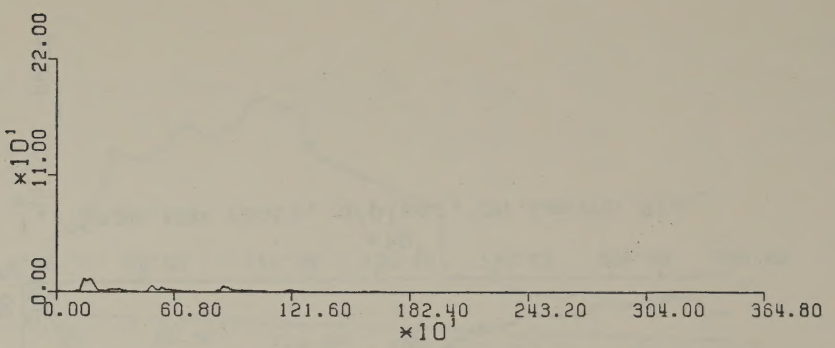


d. Litter, g/m^2, on Canyon Rim.

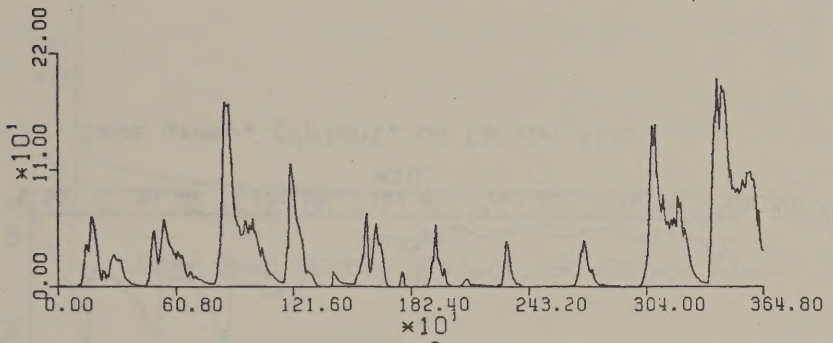
Figure 5.3. Plant submodel state variables for 10-year run without fauna. Shown are green and litter biomass for both ERUs and all species, g/m^2, and all sage state variables from Canyon Rim, g/plant. On all plots the x-axis is time in days beginning 1 January 1963.



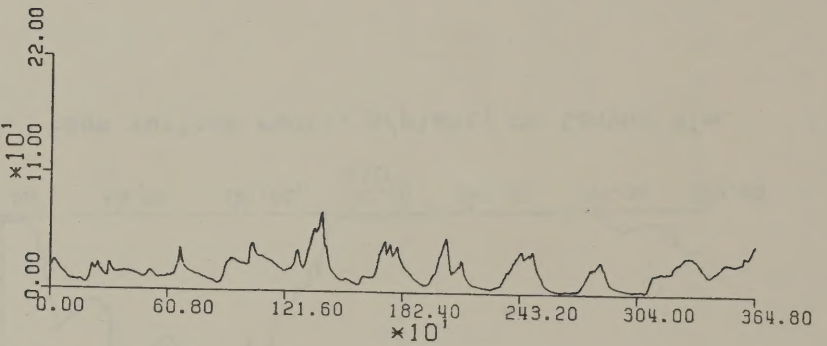
e. Sage green, g/m^2, on Main Basin.



g. Forbs green, g/m^2, on Main Basin.

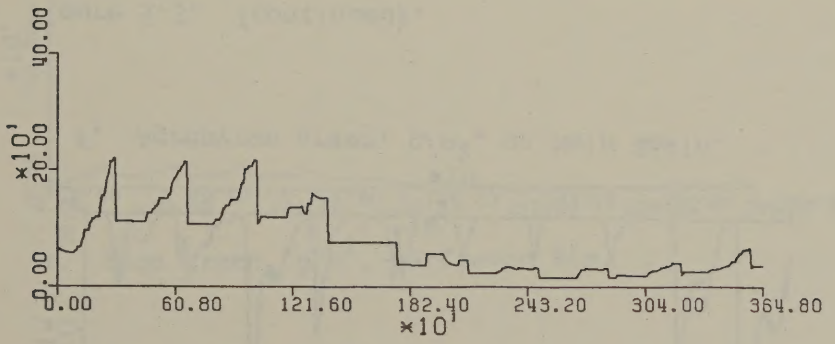


f. Agropyron green, g/m^2, on Main Basin.

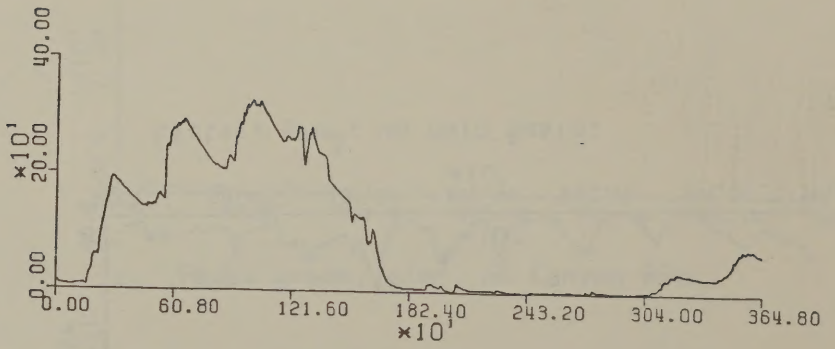


h. Litter, g/m^2, on Main Basin.

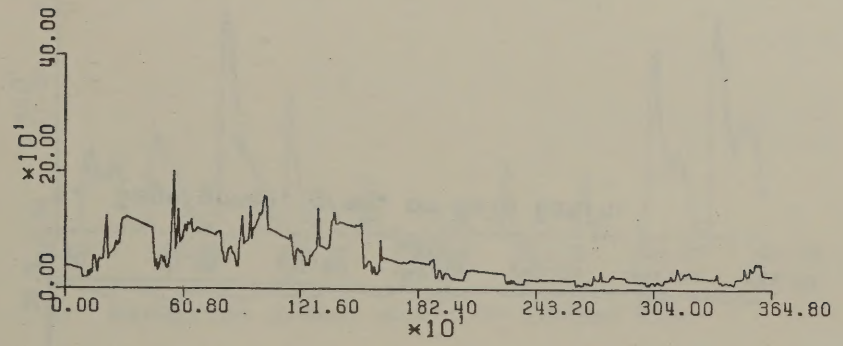
Figure 5.3. (continued).



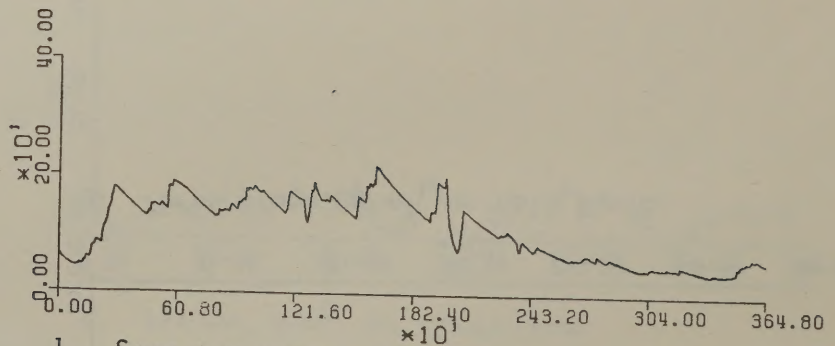
i. Sage green, g/plant, on Canyon Rim.



k. Sage surface roots, g/plant, on Canyon Rim.

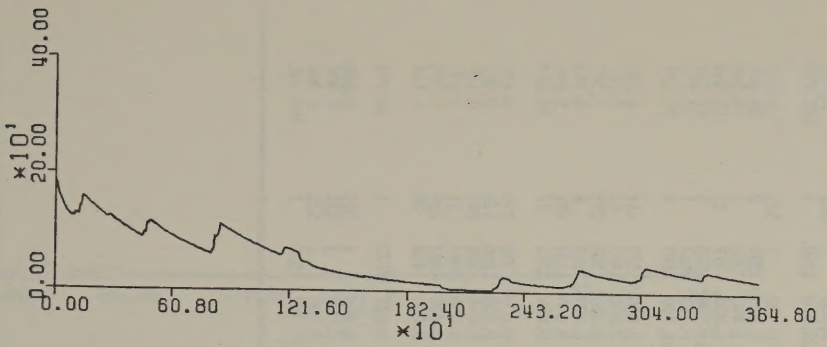


j. Sage storage, g/plant, on Canyon Rim.

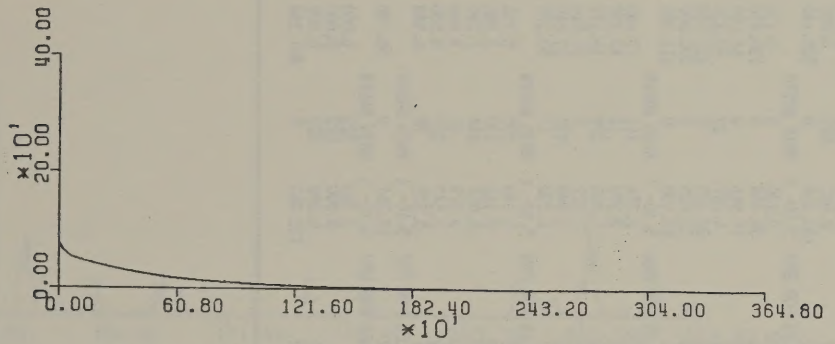


l. Sage top roots, g/plant, on Canyon Rim.

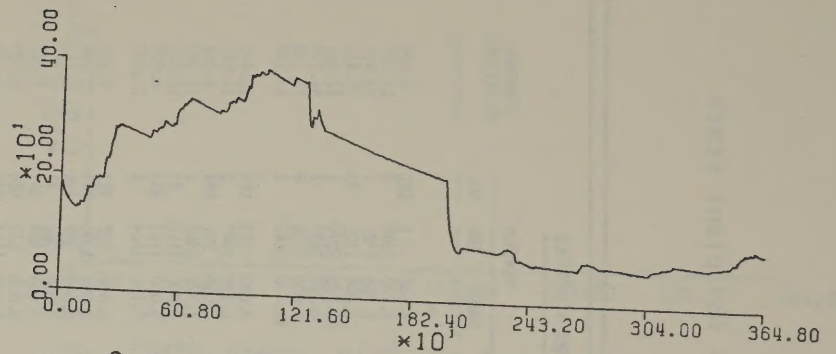
Figure 5.3. (continued).



m. Sage low roots, g/plant, on Canyon Rim.



n. Sage deep roots, g/plant, on Canyon Rim.



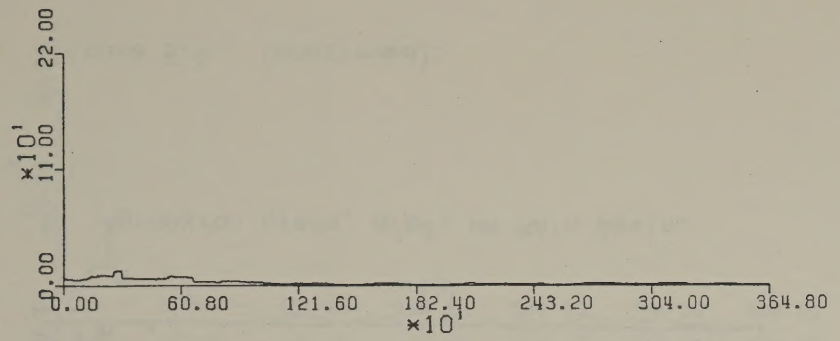
o. Sage woody, g/plant, on Canyon Rim.

Figure 5.3. (continued).

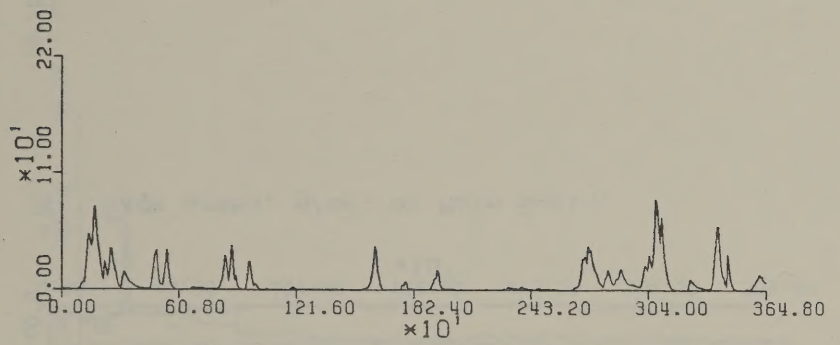
Table 5.6. Statistical summary of simulation results for plant state variables, with fauna.

AN ECOSYSTEM SIMULATION OF PERTURBATIONS PLANT-SUBMODEL STATISTICS

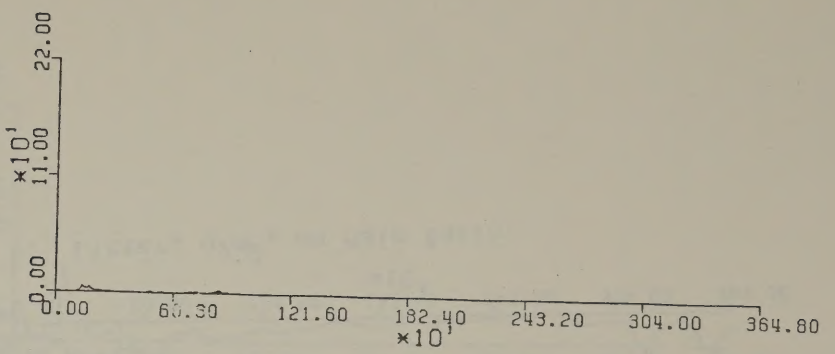
	UNITS	MEAN	ZEROES	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
				VALUE	DAY	NO.	VALUE	DAY	NO.	
SAGE . STATE VARIABLES FOR ERU	5,10- 1	CANYON RIM								
1. POPULATION	NO/M2	0.100	0	0.100	1	522	0.100	1	522	0.000
2. GREEN	G/M2	26.243	0	139.710	273	1	3.720	3640	2	26.857
3. STORAGE	G/M2	18.421	0	250.230	231	1	2.910	1981	1	23.419
4. SURROOT	G/M2	5.332	36	132.480	245	1	0.000	1323	36	15.416
5. TOPROOT	G/M2	62.764	0	221.720	546	1	15.530	3570	1	42.867
6. LOWROOT	G/M2	24.483	0	200.000	1	1	0.210	2639	2	41.270
7. DEEPROOT	G/M2	7.205	8	81.110	1	1	0.000	3598	8	14.184
8. NON-GREEN	G/M2	74.932	0	216.080	546	1	18.470	3647	1	60.289
AGROPYRON. STATE VARIABLES FOR ERU	5,10- 1	CANYON RIM								
1. GREEN	G/M2	7.437	103	85.460	3080	1	0.000	623	103	13.446
2. STORAGE	G/M2	8.761	0	94.840	3395	1	0.120	1547	2	11.547
3. SURROOT	G/M2	1.442	194	33.880	3108	1	0.000	791	194	4.054
4. TOPROOT	G/M2	24.337	0	77.630	3108	1	1.770	1568	1	16.397
5. LOWROOT	G/M2	7.932	71	43.110	2709	1	0.000	2163	71	10.443
6. DEEPROOT	G/M2	0.198	353	3.590	1	1	0.000	1183	353	0.577
7. NON-GREEN	G/M2	21.355	0	88.050	3136	1	0.120	1624	1	21.317
FORBS . STATE VARIABLES FOR ERU	5,10- 1	CANYON RIM								
1. GREEN	G/M2	0.160	352	4.980	140	1	0.000	385	352	0.590
2. STORAGE	G/M2	0.176	273	5.410	168	1	0.000	1351	273	0.396
3. SURROOT	G/M2	0.025	435	1.270	182	1	0.000	399	435	0.113
4. TOPROOT	G/M2	0.465	91	3.150	175	1	0.000	2366	91	0.802
5. LOWROOT	G/M2	0.541	291	5.500	1	1	0.000	1309	291	1.247
6. DEEPROOT	G/M2	0.009	433	0.190	1	1	0.000	623	433	0.029
7. NON-GREEN	G/M2	0.537	166	5.420	210	1	0.000	1512	166	1.106
LITTER . STATE VARIABLES FOR ERU	5,10- 1	CANYON RIM								
1. LITTER	G/M2	34.623	0	102.010	3227	1	2.710	2688	1	21.295
TOTALS STATE VARIABLES FOR ERU	5,10- 1	CANYON RIM								
1. TOTALCOVER	%	0.000	522	0.000	1	522	0.000	1	522	0.000
2. TOTLIVECOV	%	0.000	522	0.000	1	522	0.000	1	522	0.000
3. TOTALGREEN	G/M2	0.000	522	0.000	1	522	0.000	1	522	0.000
4. TOTALROOT	G/M2	134.734	0	525.640	259	1	28.070	1568	1	109.758
SAGE . STATE VARIABLES FOR ERU	5,10- 1	MAIN BASIN								
1. POPULATION	NO/M2	0.130	0	0.130	1	522	0.130	1	522	0.000
2. GREEN	G/M2	38.484	0	150.450	273	1	6.520	1596	2	28.685
3. STORAGE	G/M2	19.966	0	66.050	273	1	2.480	1596	1	14.548
4. SURROOT	G/M2	4.287	23	90.320	252	1	0.000	1379	23	10.560
5. TOPROOT	G/M2	83.805	0	227.960	532	1	16.980	1533	1	47.564
6. LOWROOT	G/M2	25.005	0	200.000	1	1	0.110	2667	1	37.770
7. NON-GREEN	G/M2	83.130	0	212.280	273	1	16.900	3647	1	57.229
AGROPYRON. STATE VARIABLES FOR ERU	5,10- 1	MAIN BASIN								
1. GREEN	G/M2	2.254	161	47.640	168	1	0.000	595	161	6.200
2. STORAGE	G/M2	2.203	12	47.250	175	1	0.000	1491	12	4.617
3. SURROOT	G/M2	0.403	299	16.210	182	1	0.000	504	299	1.547
4. TOPROOT	G/M2	7.422	0	37.810	3409	1	0.020	1533	6	8.943
5. LOWROOT	G/M2	2.989	151	21.610	147	1	0.000	1631	151	5.091
6. NON-GREEN	G/M2	6.530	17	53.270	238	1	0.000	1533	17	10.642
FORBS . STATE VARIABLES FOR ERU	5,10- 1	MAIN BASIN								
1. GREEN	G/M2	0.148	290	5.750	140	1	0.000	308	290	0.630
2. STORAGE	G/M2	0.166	133	2.950	133	1	0.000	1260	133	0.362
3. SURROOT	G/M2	0.027	444	1.290	175	1	0.000	385	444	0.129
4. TOPROOT	G/M2	0.577	21	4.860	175	1	0.000	2541	21	1.035
5. LOWROOT	G/M2	0.547	209	5.500	1	1	0.000	1407	209	1.249
6. NON-GREEN	G/M2	0.525	78	6.540	203	1	0.000	1428	78	1.164
LITTER . STATE VARIABLES FOR ERU	5,10- 1	MAIN BASIN								
1. LITTER	G/M2	14.261	0	56.780	308	1	0.920	2723	1	11.091
TOTALS STATE VARIABLES FOR ERU	5,10- 1	MAIN BASIN								
1. TOTALCOVER	%	0.000	522	0.000	1	522	0.000	1	522	0.000
2. TOTLIVECOV	%	0.000	522	0.000	1	522	0.000	1	522	0.000
3. TOTALGREEN	G/M2	0.000	522	0.000	1	522	0.000	1	522	0.000
4. TOTALROOT	G/M2	132.262	0	481.260	259	1	19.280	1533	1	103.065



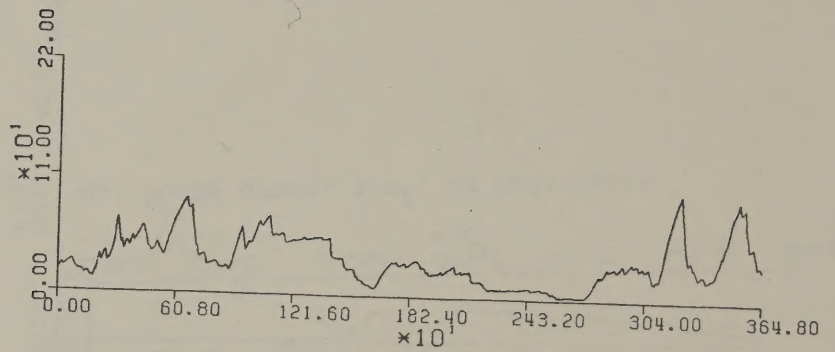
a. Sage green, g/m^2, on Canyon Rim.



b. Agropyron green, g/m^2, on Canyon Rim.

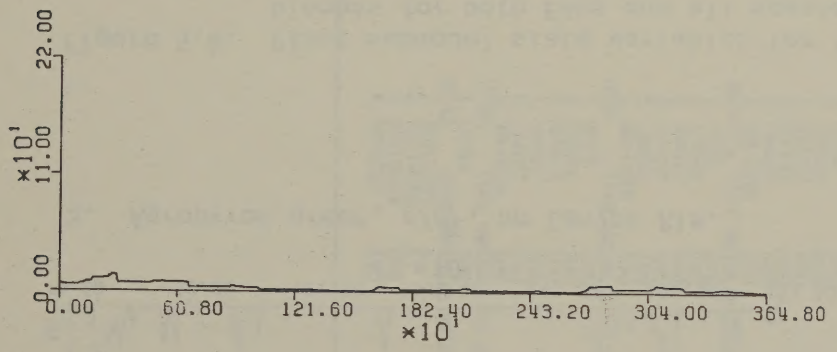


c. Forbs green, g/m^2, on Canyon Rim.

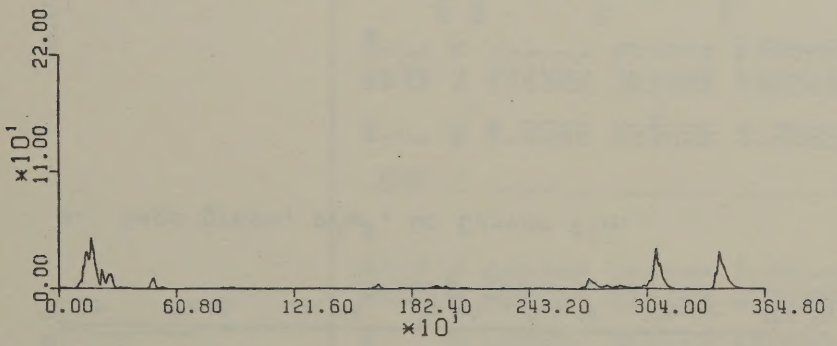


d. Litter, g/m^2, on Canyon Rim.

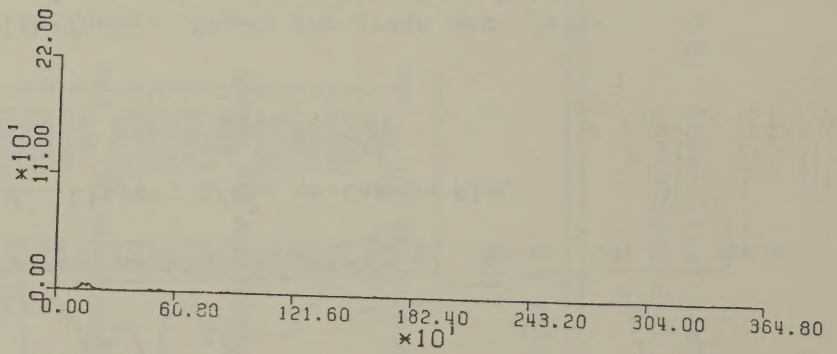
Figure 5.4. Plant submodel state variables for 10-year run with fauna. Shown are green and litter biomass for both ERUs and all species, g/m^2, and all sage state variables from Canyon Rim, g/plant. On all plots the x-axis is time in days beginning 1 January 1963.



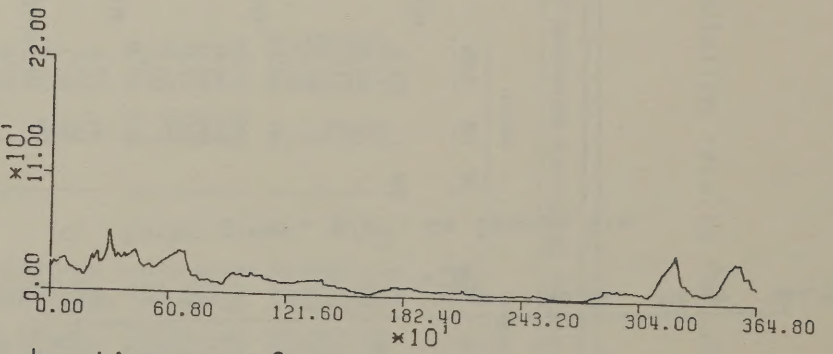
e. Sage green, g/m2, on Main Basin.



f. Agropyron green, g/m2, on Main Basin.

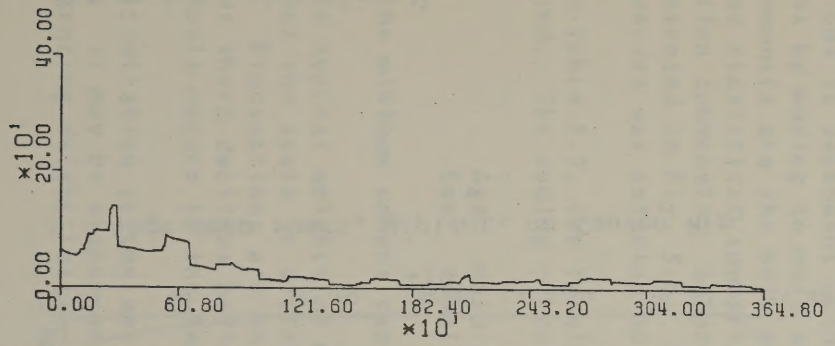


g. Forbs green, g/m2, on Main Basin.

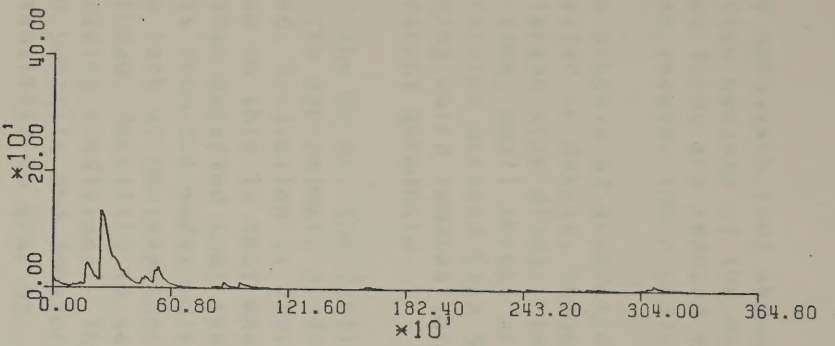


h. Litter, g/m2, on Main Basin.

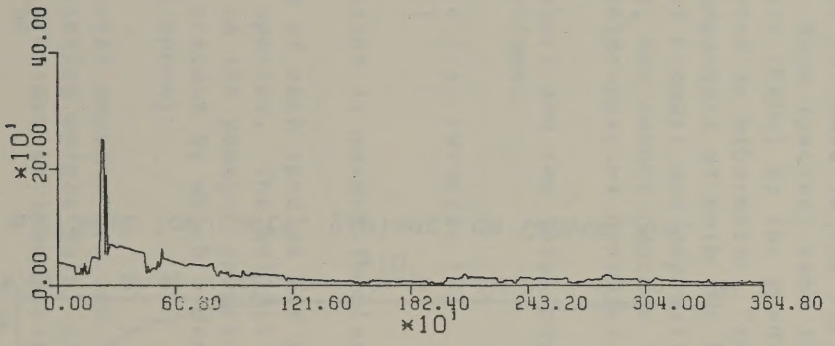
Figure 5.4. (continued).



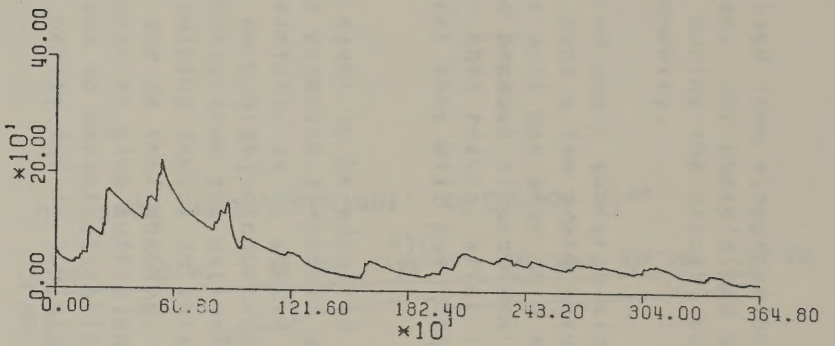
i. Sage green, g/plant, on Canyon Rim.



k. Sage surface roots, g/plant, on Canyon Rim.

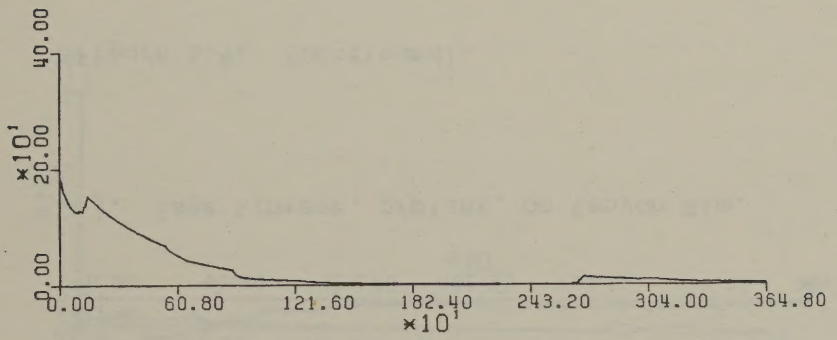


j. Sage storage, g/plant, on Canyon Rim.

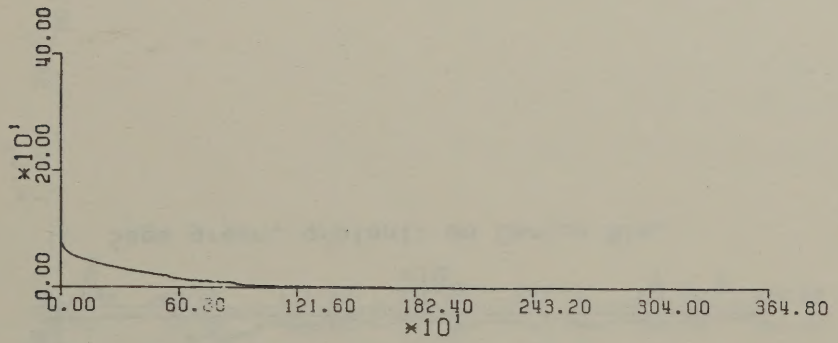


l. Sage top roots, g/plant, on Canyon Rim.

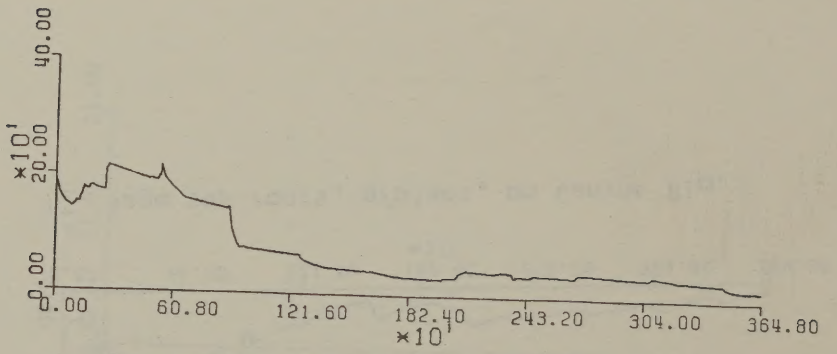
Figure 5.4. (continued).



m. Sage low roots, g/plant, on Canyon Rim.



n. Sage deep roots, g/plant, on Canyon Rim.



o. Sage woody, g/plant, on Canyon Rim.

Figure 5.4. (continued).

actually necessary (not shown). This resulted from exaggeration in root competition because of the model formulation. One unexplained occurrence is that once forbs are reduced to a low level during the drought years, they are unable to recover their position in the community.

The process of graduation of shrubs from small to large size classes was never tested in detail, though during some runs a few small shrubs did move up to the larger size class. Invasion of bare soil was also only tested briefly. At this time, small shrubs are not modelled because of problems in the animal diet selection process (see Sec. 6.3). For this reason, after the occurrence of anything which removes shrubs (e.g., fire) they will not return since large shrubs cannot germinate.

For the Garat, the fertility variable needs to be adjusted to 0.6 to achieve the approximate productivity levels expected if plants alone are simulated. Production is closely tied to rainfall, as it should be. An exception to this is that when rainfall is very high, production is much higher than expected (not shown). This results from the exclusion of soil nutrients from the model which becomes a limiting factor in this case, and from the lack of photosynthetic inhibition due to self shading. When animals are included, fertility is set to 1.2 in order to give sufficient plant growth under grazing conditions. This is partly due to unrealistically high intake rates by juvenile and immature cohorts and partly due to the plants being overly sensitive to grazing.

Litter fluctuates around a fairly stable mean value, the magnitude of which is quite reasonable.

Faunal Submodels. In general, species response to the varying ERU conditions is dependent upon the species. Some species, tend toward stable patterns by moving to more suitable habitats (ERUs) as the conditions change. Small mammals are the only species considered to hibernate. Table 5.7 provides statistical summaries of major components of both the biomass and population submodels. Selected examples of biomass and population components are presented in Fig. 5.5. For simplicity, one cohort (mature females) of each species was selected to demonstrate inter-species dynamics.

In Table 5.7, the results for each cohort and the total population are presented. The coding of cohorts is as follows:

Age: mature (0), immature (1), juvenile (2)
Sex: female (0), male (1)

Thus, the minimum cohort capable of simulation is mature females (00).

The typical weights of mature females of each species are presented. Note that the scale is different for each species. The weights are fairly stable. Fluctuations are more pronounced in the younger cohorts (not shown). Apparent sharp declines reflect the aging process by which older, and heavier, individuals mature to the next cohort (not shown).

Assimilation is the net result of several consumption and foraging processes. It may be either positive (representing weight gain) or negative (representing weight loss). Assimilation provides an interesting insight to

the species responses to ERU conditions. Differing seasonal dynamics are exhibited between ERUs and between cohorts.

The population graphs show a much greater difference is species' response to ERU conditions than do the biomass graphs due to low reproductive rates during years of low vegetative production. The more mobile species have a greater tendency toward stabilization and equalization between ERUs. Since jackrabbits breed throughout the warm months, there is a buildup of the juvenile cohort, which declines as winter conditions become more severe. Like typical weight, many of the sharp changes in population levels reflect an aging of a portion of the population to the next cohort.

Natural death is primarily caused by starvation and exposure. Severe conditions vary both between ERUs and seasonally within ERUs. The majority of the natural deaths occur during the winter months.

All predation losses shown in Table 5.7 represent predation loss to coyotes. Although the coyote population is fairly consistent among ERUs, there are very significant differences in predation pressures due to habitat characteristics, such as cover. There is also a considerable increase of predation pressure during the seasons when animals are giving birth to young.

The dispersing populations may be either positive (representing movement into an ERU) or negative (representing movement out of an ERU). Under favorable conditions, the populations tend to be more stationary, while as conditions worsen, there is a marked increase in the size of the dispersing population.

The distances traveled by individuals are fairly constant over time depending on home range site and migration, and are not plotted.

Events. It appears that the event routines all perform their functions properly. Events are sorted correctly by date and type and all execute in the correct sequence. All messages describing the operation of events are sent to output and are thus not saved on tape. The formats could be improved but are clear and informative. When events are executed they all perform their functions properly, as far as testing has gone. The process of removing animals from many pastures or moving them between pastures has not been fully tested. The only error is that executing MOVEHERD causes a data structure foul up (see Sec. 6.3 for detailed explanation). Therefore, events were not used for the test runs and their use in the context of normal operation is not illustrated.

5.3 Anslysis of Model Performance

5.3.1 Model Verification

The first verification criterion is whether the model meets the required specifications as far as processes simulated and management orientation. The specifications stated in the original contract are rather general but they seem to have been met. More specific objectives were set up by the investigators (this report, section 1.1) and these have all been met. It is

Table 5.7. Statistical summary of simulation results for fauna state variables and processes. (a) Coyote on main basin.

FAUNA SUMMARY STATISTICS

ERU : MAIN BASIN - 1

SPECIES : COYOTE .

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	35.253	17.4251	9165.70	0	81.5	1862	1	0.5	3612	3
0	1	43.243	23.9507	11243.10	0	87.9	2268	1	1.5	3626	1
1	0	30.861	31.5819	8023.90	0	226.0	1274	1	0.3	3640	1
1	1	32.035	27.8182	8329.00	0	144.9	1274	1	0.3	3556	3

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	16.407	4.0945	4265.73	0	21.8	700	1	7.6	3556	1
0	1	18.548	7.5919	4822.40	0	48.7	1	1	5.1	3640	1
1	0	10.396	2.8819	2703.06	0	17.8	1	1	4.9	3332	1
1	1	10.946	3.0017	2845.87	0	18.8	1	1	5.1	490	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.159	0.6539	-41.41	0	1.8	1568	1	-1.6	1442	1
0	1	-0.275	0.7150	-71.40	0	1.8	1568	1	-2.5	98	1
1	0	0.151	0.5987	39.13	0	1.7	1932	1	-1.0	1442	1
1	1	0.137	0.6405	35.52	1	1.8	1932	1	-1.1	3514	1

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.450	1.3718	117.12	196	9.3	1498	1	0.0	1	196
0	1	0.511	1.4413	132.74	194	8.4	1204	1	0.0	1	194
1	0	1.396	6.7923	362.88	175	37.8	1274	1	-9.3	1498	1
1	1	1.336	6.8966	347.25	171	37.8	1274	1	-8.4	1204	1

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.706	3.3854	183.60	0	30.7	1904	1	0.0	182	30
0	1	0.900	4.1013	233.99	0	31.9	1904	1	0.0	182	36
1	0	1.764	8.9813	458.74	28	118.8	1288	1	0.0	2730	28
1	1	1.872	8.9491	486.70	21	92.3	1288	1	0.0	3038	21

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.257	2.6079	66.92	0	17.4	1	1	-11.7	2030	1
0	1	0.397	3.5865	103.11	0	17.4	1	1	-19.4	2030	1
1	0	0.370	3.6326	96.29	2	38.5	1274	1	-14.1	924	1
1	1	0.537	3.7446	139.74	1	25.4	1274	1	-15.1	1260	1

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(b). Jackrabbit on main basin.

FAUNA SUMMARY STATISTICS

ERU : MAIN BASIN - 1

SPECIES : JACKRABBIT

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	331.044	540.3089	86071.40	169	1900.6	28	1	0.0	1288	169
0	1	474.531	600.9174	123378.10	0	1904.7	28	1	19.8	3626	1
1	0	5.225	27.1075	1358.60	247	224.4	364	1	0.0	1	247
1	1	104.768	265.1601	27239.80	214	1106.1	350	1	0.0	1	214
2	0	50.595	114.9692	13154.60	199	673.0	266	1	0.0	1	199
2	1	121.034	292.1261	31468.90	190	1329.9	266	1	0.0	1	190

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.641	0.8766	166.72	169	1.9	1022	2	0.0	1288	169
0	1	2.284	0.1039	593.84	0	2.3	3220	1	1.7	1554	1
1	0	0.062	0.2740	16.04	247	1.5	532	1	0.0	1	247
1	1	0.298	0.6484	77.38	214	1.9	518	1	0.0	1	214
2	0	0.041	0.1020	10.78	199	0.8	350	1	0.0	1	199
2	1	0.091	0.2074	23.60	190	1.0	700	1	0.0	1	190

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.001	0.0037	0.23	189	0.0	84	2	0.0	1274	1
0	1	0.002	0.0236	0.42	50	0.1	1596	1	-0.1	1540	1
1	0	0.003	0.0139	0.76	247	0.1	378	1	0.0	1	247
1	1	0.012	0.0282	3.14	214	0.1	364	1	0.0	1	214
2	0	0.016	0.0302	4.28	199	0.1	308	1	0.0	1	199
2	1	0.025	0.0417	6.48	190	0.1	308	1	0.0	1	190

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	2.024	16.8495	526.22	254	212.9	532	1	0.0	1	254
1	0	0.863	13.9167	224.40	259	224.4	364	1	0.0	1	259
1	1	3.702	74.5882	962.54	252	1106.1	350	1	-212.9	532	1
2	0	33.748	78.6079	8774.40	204	250.3	448	1	-224.4	364	1
2	1	28.885	107.6089	7510.04	203	250.3	448	1	-1106.1	350	1

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.361	0.6754	93.83	169	2.9	28	1	0.0	1288	169
0	1	0.865	0.8317	224.83	0	3.2	1386	1	0.0	3108	12
1	0	0.009	0.0469	2.27	248	0.4	378	1	0.0	1	248
1	1	0.160	0.4806	41.68	215	2.2	364	2	0.0	1	215
2	0	0.010	0.0387	2.56	237	0.3	280	1	0.0	1	237
2	1	0.060	0.1580	15.59	221	0.8	728	1	0.0	1	221

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	5.770	9.6752	1500.32	168	44.8	994	1	0.0	1302	168
0	1	6.460	12.2878	1679.55	149	63.9	994	1	0.0	1456	149
1	0	0.842	3.9192	219.90	247	26.9	378	1	0.0	1	247
1	1	3.691	8.5319	959.78	214	38.5	868	1	0.0	1	214
2	0	33.593	72.7459	8734.16	199	294.0	504	1	0.0	1	199
2	1	28.839	58.5942	7498.17	190	283.0	504	1	0.0	1	190

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	6.131	89.8128	1594.11	171	1191.0	1	1	-308.1	42	1
0	1	5.378	90.1297	1398.32	0	1191.0	1	1	-308.7	42	1
1	0	-0.012	0.1170	-3.24	255	0.0	1	255	-1.5	462	1
1	1	0.150	3.4582	38.89	214	23.1	378	1	-19.1	560	1
2	0	-0.143	1.7853	-37.11	206	14.9	616	1	-8.9	140	1
2	1	0.016	4.2121	4.28	194	45.0	616	1	-16.2	560	1

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(c). Small mammal on main basin.

FAUNA SUMMARY STATISTICS

ERU : MAIN BASIN - 1

SPECIES : SM. MAMMAL

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	20570.339	16346.9664	5348288.10	59	65975.3	1540	1	0.0	2492	59
0	1	35877.279	14676.2366	9328092.60	0	74170.1	1512	1	2006.8	70	1
1	0	42535.517	40375.3913	11059234.50	78	128995.8	1092	1	0.0	1	78
1	1	54020.683	43302.1509	14045377.60	43	136787.7	1344	1	0.0	1	43

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.051	0.0282	13.31	59	0.1	532	57	0.0	2492	59
0	1	0.072	0.0053	18.66	0	0.1	532	95	0.0	98	1
1	0	0.028	0.0220	7.40	78	0.1	2520	2	0.0	1	78
1	1	0.041	0.0213	10.59	43	0.1	2478	1	0.0	1	43

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.000	0.0011	0.10	217	0.0	112	1	0.0	1	217
0	1	0.000	0.0012	0.11	211	0.0	112	1	0.0	3640	1
1	0	0.002	0.0024	0.51	134	0.0	1568	1	0.0	1	134
1	1	0.002	0.0026	0.62	115	0.0	476	5	0.0	1	115

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	605.793	3346.1341	157506.23	250	30544.6	1526	1	0.0	1	250
0	1	729.357	3563.3965	189632.79	241	28018.0	1512	1	0.0	1	241
1	0	1727.397	5426.8264	449123.34	174	13011.3	1260	1	-30544.6	1526	1
1	1	1603.834	5671.5545	416996.78	164	13011.3	1260	1	-28018.0	1512	1

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	22.000	21.1302	5720.05	55	119.8	56	1	0.0	2492	55
0	1	78.545	112.9269	20421.82	0	935.0	3164	1	4.0	70	1
1	0	62.149	84.0813	16158.79	91	388.1	1092	1	0.0	1	91
1	1	80.095	93.2148	20824.68	47	419.4	1456	1	0.0	1	47

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	728.913	959.9489	189517.27	126	4749.1	1568	1	0.0	1	126
0	1	732.234	895.9489	190380.75	90	4225.9	1568	1	0.0	1	90
1	0	1821.231	2403.6886	473520.09	134	12053.6	1568	1	0.0	1	134
1	1	1668.040	2046.3701	433690.30	115	10043.0	1568	1	0.0	1	115

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	145.121	9283.1908	37731.36	53	56755.5	56	1	-57792.2	70	1
0	1	138.032	12113.5868	35888.39	0	62231.7	2226	1	-57792.2	70	1
1	0	156.232	8388.7788	40620.31	78	57422.1	2226	1	-62021.2	2212	1
1	1	144.301	13049.5705	37518.28	46	86154.0	2226	1	-112153.9	2212	1

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(d). Coyote on canyon rim.

FAUNA SUMMARY STATISTICS

ERU : CANYON RIM - 1

SPECIES : COYOTE .

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	18.560	6.7156	4825.50	0	33.7	1260	1	0.4	3640	1
0	1	25.034	11.2707	6508.80	0	52.0	2254	1	0.5	3640	1
1	0	20.508	21.3540	5332.00	0	156.8	1260	1	0.1	3640	1
1	1	27.402	26.0127	7124.40	0	111.0	1288	1	0.1	3640	1
TOTAL		91.503	55.2427	23790.70	0	329.9	1260	1	1.1	3640	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	18.811	2.4817	4890.88	0	21.9	1064	1	9.6	3374	1
0	1	22.940	8.2783	5964.37	0	49.7	1	1	10.8	3360	1
1	0	11.392	3.1111	2961.80	0	18.0	210	1	3.1	490	1
1	1	11.926	3.2385	3100.65	0	19.0	210	1	3.3	490	1
TOTAL		65.068	13.9233	16917.70	0	106.5	1	1	37.1	3360	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.005	0.5079	1.39	0	1.5	1568	1	-1.4	2898	1
0	1	-0.090	0.5846	-23.37	0	1.5	1568	1	-2.3	98	1
1	0	0.308	0.5090	80.06	0	1.6	868	1	-1.0	3640	1
1	1	0.363	0.5317	94.44	0	1.7	868	1	-1.0	3640	1
TOTAL		0.587	1.9949	152.52	0	6.1	1932	1	-4.5	84	1

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.165	0.6285	43.01	219	4.3	1218	1	0.0	1	219
0	1	0.302	1.1743	78.47	219	7.6	1876	1	0.0	1	219
1	0	1.852	5.8138	481.41	184	34.4	1260	1	-4.1	1176	1
1	1	1.715	6.0209	445.97	180	34.4	1260	1	-7.6	1876	1
TOTAL		4.034	11.6023	1048.86	220	68.9	1260	1	0.0	1	220

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.060	0.1837	15.61	5	2.3	3374	1	0.0	3500	5
0	1	0.057	0.1843	14.82	5	2.8	3374	1	0.0	3500	5
1	0	1.519	7.6208	394.95	70	103.1	1288	1	0.0	28	70
1	1	1.215	5.8124	315.96	64	55.6	1246	1	0.0	28	64
TOTAL		2.851	11.0095	741.34	2	103.2	1288	1	0.0	3500	2

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
TOTAL		0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.257	2.6079	-66.92	0	11.7	2030	1	-17.4	1	1
0	1	-0.397	3.5865	-103.11	0	19.4	2030	1	-17.4	1	1
1	0	-0.370	3.6326	-96.29	2	14.1	924	1	-38.5	1274	1
1	1	-0.537	3.7446	-139.74	1	15.1	1260	1	-25.4	1274	1
TOTAL		-1.562	12.3096	-406.06	0	51.3	2030	1	-81.0	1274	1

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(e). Bighorn on canyon rim.

FAUNA SUMMARY STATISTICS

ERU : CANYON RIM - 1

SPECIES : BIGHORN .

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	12.748	1.8926	3314.40	0	16.0	1442	3	9.1	2086	1
0	1	10.260	1.8164	2667.50	0	13.3	1106	1	7.2	2072	2
1	0	5.392	2.0003	1401.90	0	8.5	1848	4	2.2	1	34
1	1	5.207	1.5587	1353.70	0	7.3	1176	6	2.2	1	33
2	0	5.513	3.2152	1433.40	0	21.9	896	1	1.6	2646	5
2	1	5.479	1.9410	1424.50	0	13.8	1246	1	2.3	2646	3
TOTAL		44.598	6.7872	11595.40	0	70.1	1246	1	35.8	1582	2

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	272.553	23.3487	70863.66	0	286.3	994	1	137.3	1568	1
0	1	389.888	41.8211	101370.87	0	418.2	994	1	200.5	1526	1
1	0	244.718	32.2498	63626.57	0	275.0	3108	1	99.0	1526	1
1	1	341.566	54.7141	88807.15	0	402.9	1078	1	151.1	1540	1
2	0	131.076	31.2742	34079.68	0	185.6	476	1	80.1	518	1
2	1	178.753	43.4730	46475.73	0	267.2	1750	1	74.4	1540	1
TOTAL		1558.553	177.3691	405223.66	0	1791.2	812	1	803.9	1568	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	-0.222	4.6496	-57.70	1	23.8	1610	1	-13.5	1470	1
0	1	-0.320	8.4095	-83.11	0	44.2	1610	1	-19.2	1470	1
1	0	2.073	6.0378	539.01	0	37.6	1610	1	-10.1	3640	1
1	1	3.060	9.2170	795.50	0	49.8	1610	1	-17.2	1470	1
2	0	3.888	4.8887	1010.77	0	28.2	1610	1	-6.5	1470	1
2	1	5.982	7.4389	1555.26	0	43.3	1610	1	-9.3	1470	1
TOTAL		14.460	37.7631	3759.72	0	226.9	1610	1	-75.6	1470	1

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.038	0.2582	9.79	254	2.6	1442	1	0.0	1	254
0	1	0.030	0.2176	7.80	255	2.1	1106	1	0.0	1	255
1	0	0.018	0.3859	4.68	243	2.5	1512	1	-2.6	1442	1
1	1	0.034	0.4336	8.95	244	4.6	1176	1	-2.1	1106	1
2	0	0.249	0.9037	64.83	216	3.2	518	1	-2.5	1512	1
2	1	0.241	0.9510	62.55	216	3.2	518	1	-4.6	1176	1
TOTAL		0.610	1.7067	158.60	227	6.5	518	1	0.0	1	227

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.050	0.3713	13.00	10	6.0	1582	1	0.0	1638	10
0	1	0.041	0.2993	10.58	19	4.8	1540	1	0.0	1638	19
1	0	0.011	0.1190	2.81	170	1.9	1540	1	0.0	1	170
1	1	0.019	0.1818	4.94	172	2.4	1540	1	0.0	1	172
2	0	0.243	1.2478	63.07	73	13.3	910	1	0.0	210	73
2	1	0.233	1.0836	60.47	68	9.5	1260	1	0.0	182	68
TOTAL		0.596	2.0962	154.87	7	19.1	1260	1	0.0	1638	7

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
2	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
2	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
TOTAL		0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
2	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
2	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
TOTAL		0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(f). Mule deer on canyon rim.

FAUNA SUMMARY STATISTICS

ERU : CANYON RIM - 1

SPECIES : MULE DEER.

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	8.652	7.1699	2249.40	44	18.9	1	2	0.0	3038	44
0	1	4.173	2.8517	1084.90	0	8.6	1078	1	0.3	3290	26
1	0	0.911	1.5485	236.90	187	4.7	1	1	0.0	1036	187
1	1	1.986	2.4913	516.30	149	6.9	826	1	0.0	1568	149
2	0	2.014	2.6590	523.70	138	12.0	182	1	0.0	1064	138
2	1	3.005	3.6130	781.40	116	14.2	168	1	0.0	1400	116
TOTAL		20.741	18.6616	5392.60	0	55.4	168	1	0.3	3290	26

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	55.624	24.6347	14462.17	42	69.7	896	1	0.0	3066	42
0	1	148.702	16.6235	38662.47	0	169.1	896	1	97.8	1554	1
1	0	16.897	27.3212	4393.32	187	67.1	854	1	0.0	1036	187
1	1	58.826	69.1773	15294.72	148	161.4	1036	1	0.0	1582	148
2	0	9.918	14.6179	2578.81	136	45.1	854	1	0.0	1078	136
2	1	28.369	35.2724	7375.90	115	108.3	812	1	0.0	1400	115
TOTAL		318.336	160.8212	82767.39	0	614.9	812	1	109.7	3626	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.016	0.7651	4.13	41	1.5	2100	1	-4.5	2002	1
0	1	-0.028	3.0031	-7.18	0	11.9	1	1	-9.3	1274	1
1	0	0.170	0.6311	44.14	186	6.9	994	1	-0.1	28	1
1	1	0.577	2.1008	150.02	147	14.7	1	1	-6.6	1540	1
2	0	0.429	0.6812	111.65	135	2.7	2100	1	-0.1	602	1
2	1	1.392	1.9154	362.03	114	7.0	896	1	-4.1	1316	1
TOTAL		2.557	5.7489	664.80	0	27.4	1	1	-19.8	1274	1

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.004	0.0595	0.96	259	1.0	980	1	0.0	1	259
0	1	0.010	0.1656	2.67	259	2.7	1078	1	0.0	1	259
1	0	0.002	0.0965	0.50	257	1.2	504	1	-1.0	980	1
1	1	0.015	0.2885	3.78	256	2.6	1162	1	-2.7	1078	1
2	0	0.247	0.9318	64.27	232	4.5	182	1	-1.2	504	1
2	1	0.228	0.9631	59.28	231	4.5	182	1	-2.6	1162	1
TOTAL		0.506	1.8543	131.46	234	8.9	182	1	0.0	1	234

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.016	0.0142	4.27	74	0.1	1876	6	0.0	1638	74
0	1	0.007	0.0074	1.86	111	0.0	2156	7	0.0	182	111
1	0	0.000	0.0016	0.07	253	0.0	1	7	0.0	84	253
1	1	0.001	0.0031	0.27	233	0.0	1	27	0.0	84	233
2	0	0.113	0.6910	29.48	207	6.4	168	1	0.0	182	207
2	1	0.142	1.0245	36.97	187	9.7	182	1	0.0	196	187
TOTAL		0.280	1.4325	72.92	61	13.5	546	1	0.0	1638	61

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.060	0.0770	15.62	93	0.5	1624	1	0.0	182	93
0	1	0.030	0.0416	7.87	91	0.3	1624	1	0.0	182	91
1	0	0.019	0.0455	5.03	204	0.3	994	1	0.0	182	204
1	1	0.031	0.0685	8.09	171	0.4	1526	1	0.0	182	171
2	0	0.160	0.5307	41.47	188	4.2	1358	1	0.0	182	188
2	1	0.111	0.2867	28.89	167	2.5	1624	1	0.0	182	167
TOTAL		0.411	0.8460	106.97	91	5.8	1260	1	0.0	182	91

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM VALUE	MAXIMUM DAY	MAXIMUM NO	MINIMUM VALUE	MINIMUM DAY	MINIMUM NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
2	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
2	1	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
TOTAL		0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(g). Jackrabbit on canyon rim.

FAUNA SUMMARY STATISTICS

ERU : CANYON RIM - 1

SPECIES : JACKRABBIT

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	210.771	349.3574	54800.50	175	1446.7	1	1	0.0	1204	175
0	1	294.173	375.8736	76485.10	0	1448.3	1	1	11.6	3640	1
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	60.097	145.3348	15625.10	213	643.8	350	1	0.0	1	213
2	0	27.768	63.8310	7219.80	207	278.3	266	1	0.0	1	207
2	1	79.441	191.7343	20654.60	196	856.3	630	1	0.0	1	196
TOTAL		672.250	1004.2898	174785.10	0	3066.1	266	1	11.6	3640	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.599	0.8615	155.61	175	1.9	910	13	0.0	1204	175
0	1	2.301	0.0607	598.17	0	2.3	1736	9	2.0	1	1
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.301	0.6474	78.18	213	1.9	518	1	0.0	1	213
2	0	0.030	0.0673	7.80	207	0.4	308	1	0.0	1	207
2	1	0.085	0.2022	22.05	196	1.0	756	1	0.0	1	196
TOTAL		3.315	1.5613	861.80	0	6.9	672	1	2.2	1540	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.001	0.0032	0.27	208	0.0	84	2	0.0	1092	1
0	1	0.001	0.0167	0.34	43	0.0	1554	2	-0.1	3640	1
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	0.012	0.0285	3.23	213	0.1	364	1	0.0	1	213
2	0	0.014	0.0286	3.72	207	0.1	322	1	0.0	1	207
2	1	0.023	0.0409	5.97	196	0.1	308	1	0.0	1	196
TOTAL		0.052	0.0906	13.53	42	0.3	630	1	-0.1	3640	1

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
0	1	1.017	8.1756	264.42	254	103.9	532	1	0.0	1	254
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	2.672	43.9285	694.62	251	643.8	350	1	-103.9	532	1
2	0	22.091	49.7838	5743.58	211	169.1	266	1	0.0	1	211
2	1	18.402	67.0624	4784.54	208	169.1	266	1	-643.8	350	1
TOTAL		44.181	99.5675	11487.16	211	338.2	266	1	0.0	1	211

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.241	0.4588	62.58	172	2.8	1218	1	0.0	1204	172
0	1	0.526	0.4230	136.77	0	2.2	1	1	0.0	2842	17
1	0	0.012	0.1166	3.23	255	1.5	462	1	0.0	1	255
1	1	0.090	0.2589	23.46	214	1.2	364	1	0.0	1	214
2	0	0.008	0.0407	2.07	234	0.4	1246	1	0.0	1	234
2	1	0.046	0.1198	11.95	218	0.6	532	2	0.0	1	218
TOTAL		0.923	1.0829	240.06	0	5.0	462	1	0.0	2842	17

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	3.813	6.8400	991.29	174	33.7	1008	1	0.0	1218	174
0	1	5.253	9.8200	1365.67	61	65.2	1204	1	0.0	2240	61
1	0	0.000	0.0000	0.00	260	0.0	1	260	0.0	1	260
1	1	2.432	5.6343	632.27	213	27.0	868	1	0.0	1	213
2	0	22.226	48.4591	5778.63	207	198.6	504	1	0.0	1	207
2	1	18.338	36.8102	4767.99	196	152.6	140	1	0.0	1	196
TOTAL		52.061	94.1544	13535.85	61	374.4	504	1	0.0	2240	61

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-6.131	89.8128	-1594.11	171	308.1	42	1	-1191.0	1	1
0	1	-5.378	90.1297	-1398.32	0	308.7	42	1	-1191.0	1	1
1	0	0.012	0.1170	3.24	255	1.5	462	1	0.0	1	255
1	1	-0.150	3.4582	-38.89	214	19.1	560	1	-23.1	378	1
2	0	0.143	1.7853	37.11	206	8.9	140	1	-14.9	616	1
2	1	-0.016	4.2121	-4.28	194	16.2	560	1	-45.0	616	1
TOTAL		-11.520	180.8578	-2995.25	0	616.8	42	1	-2382.0	1	1

DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259

Table 5.7(h). Small mammal on canyon rim.

FAUNA SUMMARY STATISTICS

ERU : CANYON RIM - 1

SPECIES : SM. MAMMAL

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	12019.805	10094.6515	3125149.40	47	59237.0	70	1	0.0	2520	47
0	1	20099.888	9348.7582	5225970.90	0	70930.0	2212	1	1563.5	56	1
1	0	24366.278	23805.9132	6335232.30	78	80440.2	980	1	0.0	1	78
1	1	30009.875	25652.3001	7802567.40	49	98196.0	2212	1	0.0	1	49
TOTAL		86495.846	58759.6717	22488920.00	0	255999.0	2212	1	3127.0	56	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.054	0.0260	14.14	47	0.1	532	61	0.0	2520	47
0	1	0.072	0.0052	18.67	0	0.1	532	98	0.0	98	1
1	0	0.028	0.0221	7.40	78	0.1	2520	2	0.0	1	78
1	1	0.039	0.0218	10.14	49	0.1	2492	1	0.0	1	49
TOTAL		0.194	0.0626	50.35	0	0.3	1428	2	0.1	3360	2

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0011	0.10	216	0.0	112	1	0.0	1	216
0	1	0.000	0.0012	0.11	210	0.0	112	1	0.0	3640	1
1	0	0.002	0.0024	0.51	134	0.0	1568	1	0.0	1	134
1	1	0.002	0.0027	0.61	121	0.0	2660	1	0.0	1	121
TOTAL		0.005	0.0063	1.33	115	0.0	1568	1	0.0	3640	1

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	308.145	1631.5569	80117.59	250	13126.7	1526	1	0.0	1	250
0	1	373.162	1881.2033	97022.01	244	19333.3	2212	1	0.0	1	244
1	0	1181.186	3110.2982	307108.38	174	7916.7	1638	1	-13126.7	1526	1
1	1	1116.169	3327.2599	290203.96	167	7916.7	1638	1	-19333.3	2212	1
TOTAL		2978.661	5065.9329	774451.94	183	15833.4	1638	1	0.0	1	183

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	12.302	13.5840	3198.63	48	118.7	70	1	0.0	2520	48
0	1	45.107	78.0069	11727.92	0	539.7	3094	1	1.3	84	1
1	0	32.814	40.3044	8531.67	92	196.9	2212	1	0.0	1	92
1	1	41.599	46.7579	10815.82	50	353.6	2212	1	0.0	1	50
TOTAL		131.823	111.0561	34274.04	0	696.9	2212	1	2.6	84	1

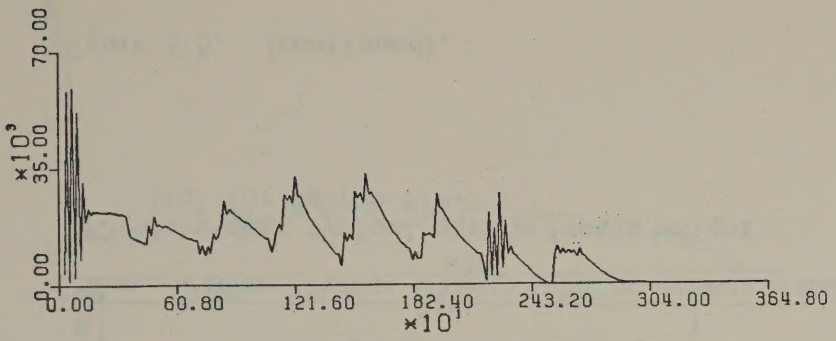
PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	388.645	473.5542	101047.62	123	1937.7	1288	1	0.0	1	123
0	1	406.744	445.0026	105753.43	90	1807.8	1288	1	0.0	1	90
1	0	992.038	1274.8632	257929.90	134	5629.8	182	1	0.0	1	134
1	1	930.269	1122.2863	241869.83	121	5440.6	182	1	0.0	1	121
TOTAL		2717.695	3169.4514	706600.83	90	12326.0	1288	1	0.0	1	90

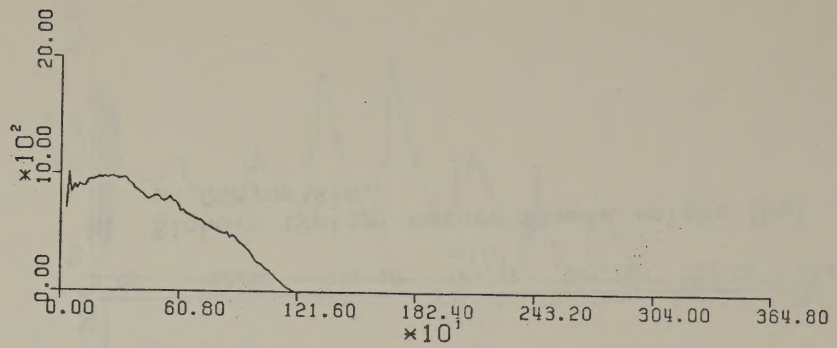
DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-145.121	9283.1908	-37731.36	53	57792.2	70	1	-56755.5	56	1
0	1	-138.032	12113.5868	-35888.39	0	57792.2	70	1	-62231.7	2226	1
1	0	-156.232	8388.7788	-40620.31	78	62021.2	2212	1	-57422.1	2226	1
1	1	-144.301	13049.5705	-37518.28	46	112153.9	2212	1	-86154.0	2226	1
TOTAL		-583.686	37012.9443	-151758.34	0	243851.5	2212	1	-224605.3	2226	1

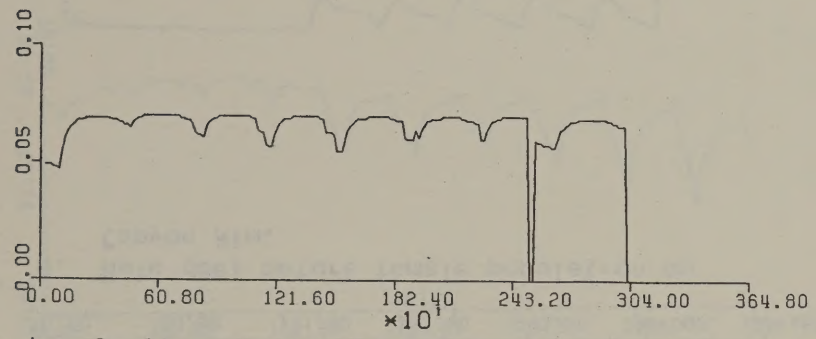
DURATION : 3640 DAYS TIME STEP : 14 DAYS INTERVALS : 259



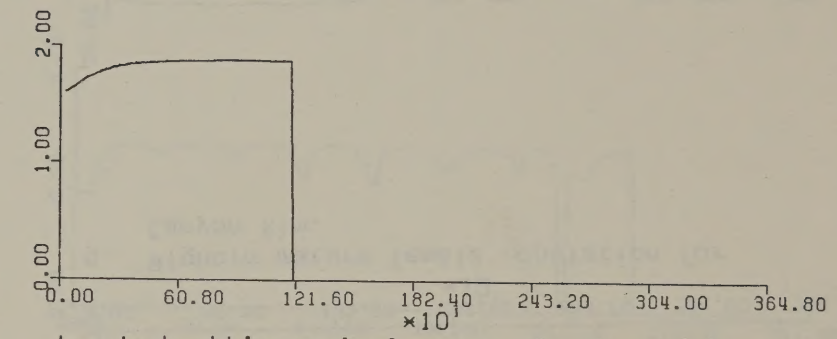
a. Small mammal mature female population for Canyon Rim.



c. Jackrabbit mature female population for Canyon Rim.

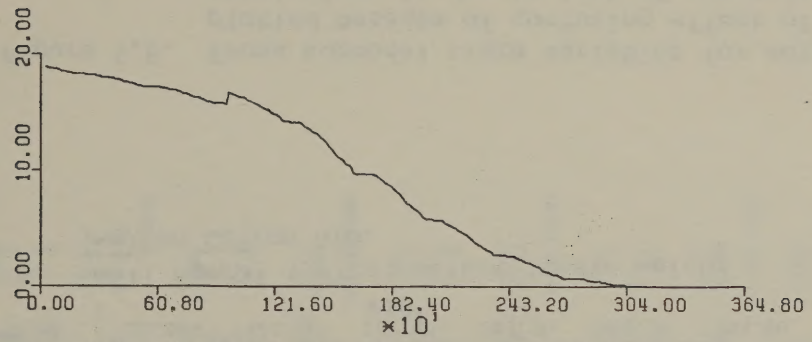


b. Small mammal typical mature female weight (kg) on Canyon Rim.

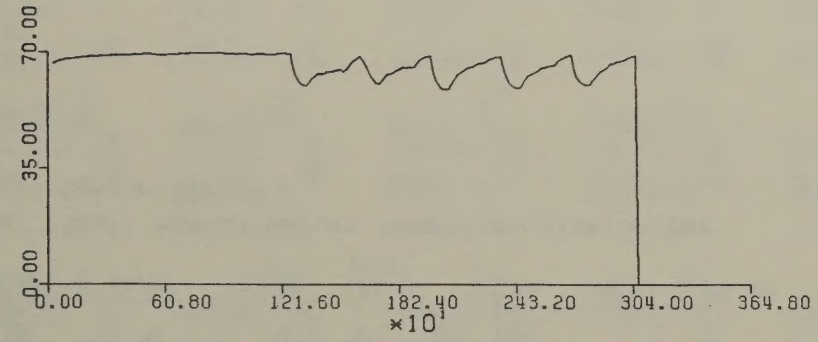


d. Jackrabbit typical mature female weight (kg) on Canyon Rim.

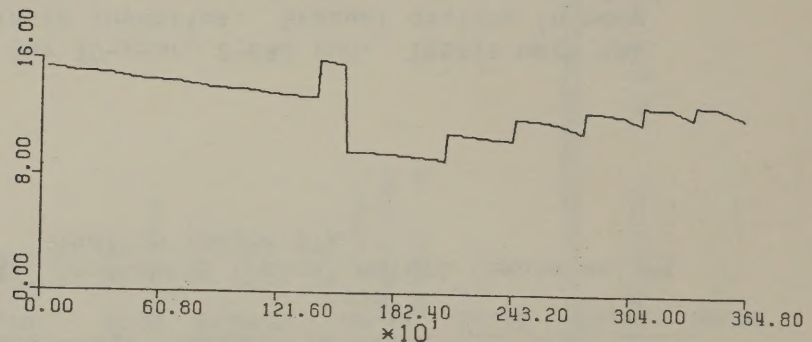
Figure 5.5. Fauna submodel state variables for mature females for 10-year, 2-ERU run. Totals were not plotted because of confusing effect of large shifts in juveniles. Gradual decline in many populations is due to lack of adequate survivorship of young cohorts due to inadequate food. Note different scales. X-axis is time in days since 1 January 1963.



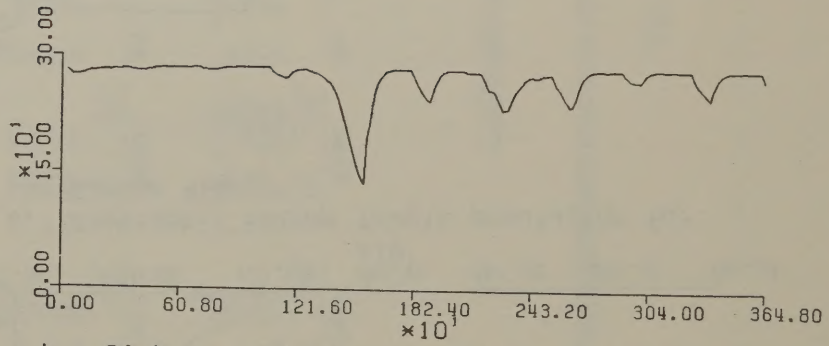
e. Mule deer mature female population on Canyon Rim.



f. Mule deer typical mature female weight (kg) for Canyon Rim.

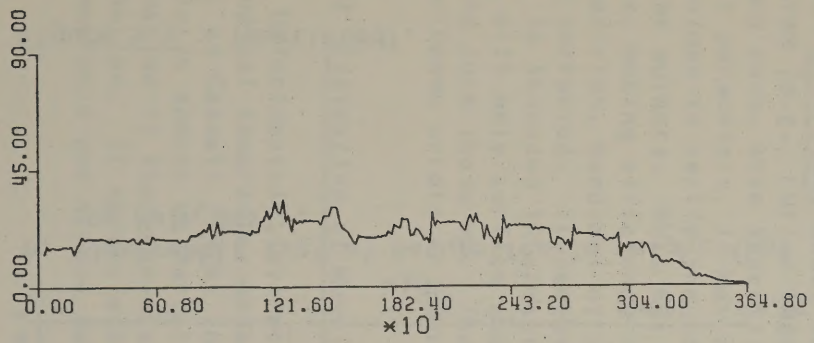


g. Bighorn mature female population for Canyon Rim.

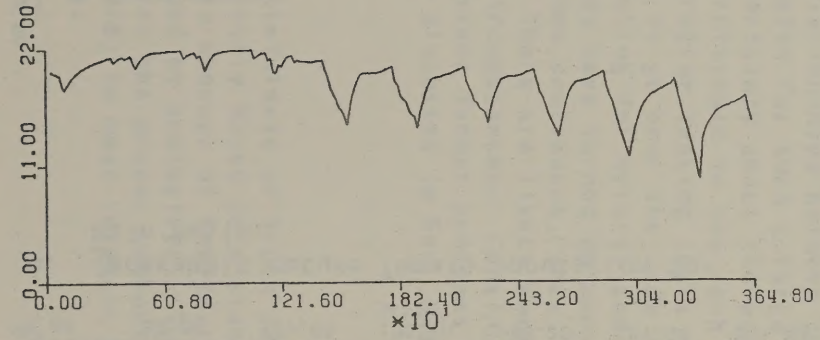


h. Bighorn typical mature female weight (kg) on Canyon Rim.

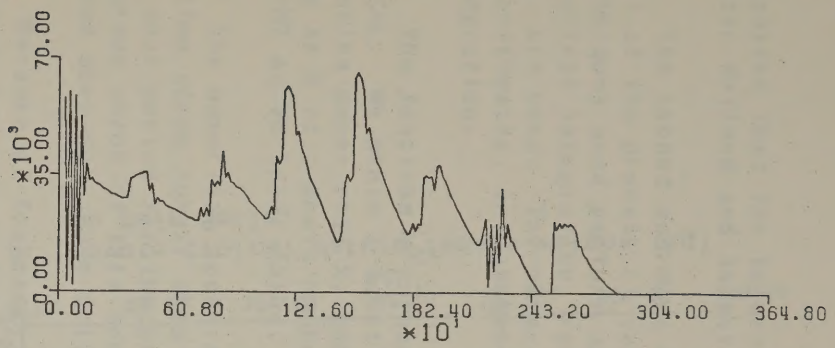
Figure 5.5. (continued).



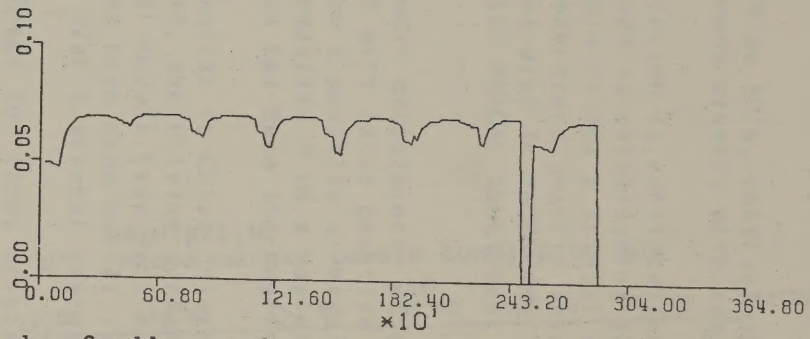
i. Coyote mature female population for Canyon Rim.



j. Coyote typical mature female weight (kg) on Canyon Rim.

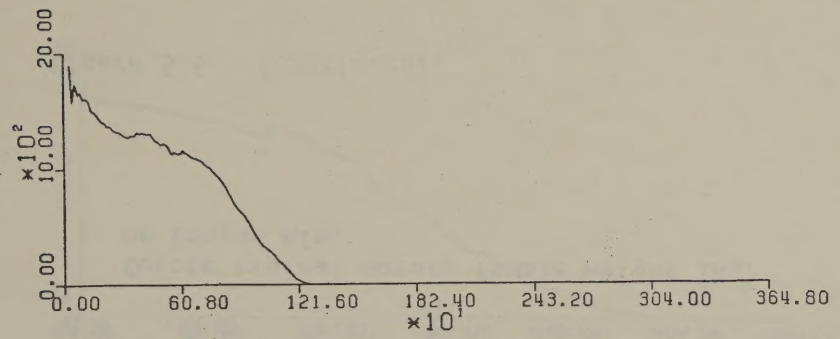


k. Small mammal mature female population for Main Basin.

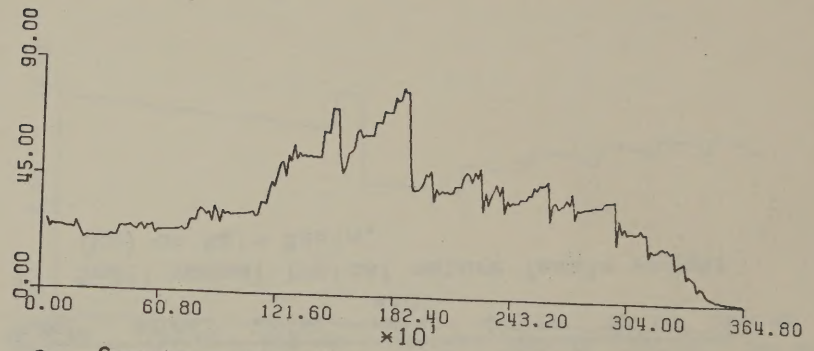


l. Small mammal typical mature female weight (kg) on Main Basin.

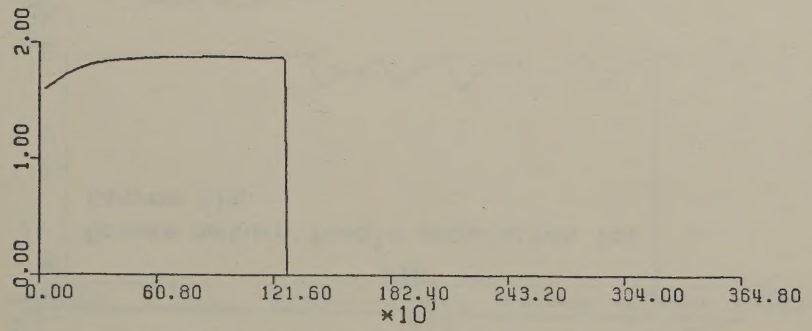
Figure 5.5. (continued).



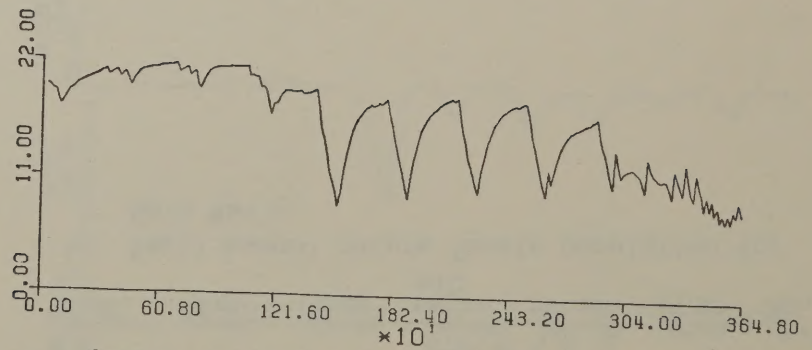
m. Jackrabbit mature female population for Main Basin.



o. Coyote mature female population for Main Basin.



n. Jackrabbit typical mature female weight (kg) on Main Basin.



p. Coyote typical mature female weight (kg) on Main Basin.

Figure 5.5. (continued).

suggested that for future projects such as this, contract specifications be better defined and investigators work more closely with agency staff.

The second and more difficult criterion is verification of model code. Part of the process of verifying the code is establishing that the numerical techniques used perform adequately. This is not a trivial consideration when numerical integration, random number generators, matrix inversion programs, etc. are used. The numerical techniques used in SAGEGRASS, aside from built in arithmetic, trigonometric, and logical PASCAL functions, are Y^X and integration.

The function Y^X, though found on most calculators, is not provided by PASCAL. We wrote a function YTOX which will raise positive Y to a positive or negative power real X, and negative Y to a positive or negative power X as long as X is a whole number. Raising negative Y to a non-whole value yields MAXINT as an error value. This function has been thoroughly checked.

The numerical technique used is similar to Euler integration except that if time steps longer than 1 day are used, the driving variables are averaged for that period for the plant and animal models (see Sec. 4.3.1.1). A rigorous check of this technique has not been done but it is known that the method does not cause drift or blow up over a several year simulation period.

Because of feedback, the use of checks for flows or state variables out of range (negative, for example), and 15 significant digits on the CDC CYBER 171, it is not expected that round off errors will be appreciable.

Another part of code verification is showing that the code is correct. It is clear that the formal technique of "program proving" involving input/output assertions about the logical relationships between the variables of the program (e.g., Cutler 1980) is too complex for such a large program as this. In any case, when there is so much uncertainty about the equations used and their parameters, it may not be very profitable to use such a sophisticated technique to verify the code. Other program testing tools were not available to the authors. What has been done is to go over the code in detail many times, making efficiency changes, searching for errors, and examining logic. In addition, hundreds of simulation runs have turned up many errors which have been corrected. It can be said with some confidence, then, that the code does what is intended in almost all cases. There are likely some hidden errors that will only surface under unusual circumstances. Continued model usage should turn these up. There are some minor format problems on output tables. Other known errors or improvements are discussed in Sec. 6.3.

5.3.2 Evaluation of Models

Unfortunately, evaluation of the usefulness or truth content of an ecological simulation model is not currently based on a standard procedure. In fact, as Caswell (1976) shows, the whole concept of "validation" of ecological models is almost universally misconstrued by ecologists. The following discussion is thus necessary to establish the proper methods for model evaluation. It agrees with Caswell (1976) in most respects but goes beyond his analysis and treats some new topics.

The basic distinction, which is often not made, is between theoretical models (theories) and predictive models (calculation tools). Validation of a theory is the problem of induction and Popper (1963) has shown that there is no valid technique for proving the truth of any theory via induction. Instead, we can corroborate our theories as they pass more and more stringent tests but this only increases our confidence and can never be absolute proof. In contrast, predictive models (calculation tools) are judged as to usefulness based on how accurately they can predict aspects of the real world or on how well they meet design specification.

Confusion has arisen in the ecological literature due to a failure to distinguish between these two classes of models. Goodness of fit to ecological data is taken as the main criteria for model evaluation (Caswell 1976). The problem is that goodness of fit is necessary but not sufficient as a criterion for evaluation of a theory. We can accept a predictive model as being sufficiently accurate but we can only fail to reject a theory.

It is not sufficient to say that our models are invalid (because not perfect) but useful, as stated by Mankin et al. (1975) because this blurs the distinction between theories and calculation tools. A good theory should do more than just predict, it should explain. It's structure should be interpretable in terms of the real world. Thus, generally, a multiple regression model would not be a good theory because the regression coefficients have no biological interpretation.

The root dynamics model of Ares and Singh (1974) is a good example of the danger of failure to distinguish theory from curve fitting. Seven of their seventeen process equations are discontinuous functions. All are functions of time. Because they fit these functions to their data, they were able to get reasonable seasonal dynamics. The problem arises because they state that this model can (i) synthesize the available knowledge into a conceptual framework and (ii) indicate the critical rate processes. The fact that the data has been fit by a type of state variable model seems to indicate that explanation has taken place. However, a model with functions based entirely on time clearly does not explain the mechanisms involved. Changes in the system that are actually responses of the plant to changes in the environment are modelled as phenological functions, leading us to expect some sort of elaborate timing apparatus within the plant. A delay in spring due to a long winter or an early summer dry spell would yield data that could not be fit at all by this model. Thus, this model is based on a faulty conceptual framework if the intent is to explain rather than just fit the data. Mechanisms postulated by the model (many biological clocks) should be tested before the next step (discovering critical rate processes) is undertaken.

Many other examples could be given of ecological models with biologically uninterpretable parameters, unmeasurable state variables, or ones that are just untestable. If these models have prediction as their sole purpose there is no problem, but treating them as theories and drawing conclusions about the real system from them is hazardous and obscures the distinction between an ad hoc model and a good theory. It will be shown below that these two types of models require very different tests of their "goodness."

Logical models are one further type of model which must be treated before examining the evaluation techniques that are appropriate. Certain types of

simulation models embody logical structures exclusively (except for I/O). Thus, a simulation of a mechanical telephone switching system, a chess playing computer program, and a simulator of a computer operating system all share the characteristics that they are logical operators and may perform their tasks exactly. This distinguishes them from any theory or calculation tool which can only approximate reality. As long as we ask the computer to do bookkeeping, for example, it does what it is supposed to do exactly. The classes of behaviors which may be modelled in this way include certain machines which perform binary operations (player pianos, coin sorters, switching networks, etc.), and mental processes or algorithms which follow rigid logical sequences such as payroll systems. Few, if any, ecological systems belong to this set.

We thus arrive at three types of simulation models: logical, theoretical, and predictive. These are the ideal types proposed but, of course, many actual models are some combination of the three. The discussion which follows assumes these ideal types.

The method used for evaluation of the quality, usefulness, or truthfulness of a simulation model will differ for each of the three model types discussed above. To avoid terminological confusion in what follows, standard definitions involved in model evaluation are taken from Innis et al. (1977):

> Reality: An entity, situation, or system which has been selected for analysis. (Its characteristics are established by observational or experimental data--both qualitative and quantitative.)
>
> Conceptual Model: The verbal description, equations, governing relationships, or physical laws that purport to describe the behavior of some or all of the aspects of an entity, situation or system. (The characterization usually reflects the intended use for which the model was developed.)
>
> Domain of Applicability of the Conceptual Model: The prescribed set of conditions for which the Conceptual Model is intended to match Reality. (Specific selection of the value of model parameters should be identified to match the prescribed conditions.)
>
> Range of Accuracy of the Conceptual Model: An indication of the expected agreement between the Conceptual Model and Reality, consistent with a given Domain of Applicability.
>
> Computer Simulation: The computerized implementation of a Conceptual Model.
>
> Simulation Verification: The process which generates evidence that a Computer Simulation represents a Conceptual Model within prescribed limits of accuracy, i.e., the computerized implementation conforms to its design objectives.

Domain of Applicability of the Computer Simulation: The prescribed set of conditions for which the Computer Simulation is intended to match Reality.

Range of Accuracy of the Computer Simulation: An indication of the expected agreement between the Computer Simulation and Reality, consistent with a given Domain of Applicability.

Simulation Validation: The process which generates evidence that the Computer Simulation possess a Range of Accuracy within a prescribed set of limits, consistent with a given Domain of Applicability. (Selection of a suitable Domain of Applicability and Range of Accuracy should reflect the purpose for which the simulation is intended.)

Simulation Certification: The process by which a Computer Simulation is declared to be usable for a specified class of studies or purposes. The certification process culminates in the creation of a document which includes:

(1) a description of the Conceptual Model and its computerized implementation

(2) a statement of the simulation's Domain of Applicability and Range of Accuracy

(3) A description of the Simulation Vertification and Validation procedures actually employed along with a critical evaluation of the adequacy of the tests and a discussion of the test results.

Testing a Logical Model. This type of model may be evaluated by the usual "validation" techniques extant in the computer science literature (Innis et al. 1977). Some of these models may be perfectly valid in the sense of no error in their predictions or operation. Others may have varying degrees of usefulness based on comparison with design specification. It is not appropriate to use techniques applicable to this class of model to evaluate theory. Taking concepts from the computer science validation literature and applying them to biological simulation models is not justified and has added to the confusion about how we should evlauate such models. Since ecological systems do not fall in this class, this type of model will not be discussed further.

Testing a Theoretical Model. Before tests of the theory embodied by a simulation model are begun, the possibility of confounding sources of error should be examined. There are three main sources of possible error: inaccurate translation of the theory into mathematical form, coding errors, and failure of numerical techniques to calculate answers correctly. Due to the lack of mathematical sophistication in the field of ecology, it is not

uncommon for a theory to be expressed in an inappropriate mathematical form. Templeton and Lawlor (1981), for example, cite several examples of the "fallacy of the average" in the formulation of ecological optimization models. Clearly, conclusions about a theory should not be drawn from the results of an incorrectly formulated model. The other two types of error should be eliminated during the simulation verification process.

Once there is confidence that the model is correctly formulated and coded, it is possible to use the model to test the theory. However, as Caswell (1976) points out, it is not very useful to just generate a time series of state variables and reject or accept the whole model based on some statistical criteria of goodness of fit. Rather, the application of "strong inference" (Platt 1964) is required. This process involves

i. devising alternative hypotheses,
ii. devising a crucial experiment, the outcome of which will exclude at least one of the hypotheses,
iii. carrying out the experiment, and
iv. returning to (i), refining the problem further.

This process never ends because our theories never capture reality perfectly. The effective application of this process in ecology via the use of models is admirably treated in Caswell (1976).

Testing predictive models. There can be no one method for testing the adequacy of predictive models because adequacy (credibility, validity) depends on the purpose of the project and the time and money constraints involved. Project objectives define the ideal domain of applicability. Thus, one test criteria is how well the model covers the domain. There may be regions of the ideal domain that are covered poorly or not at all but results in the region that is covered may still be useful to the user. It should be made clear to the user, however, what the realized domain is. Within the realized domain, various output variables may have different degrees of accuracy. Describing the extent of agreement between reality and the simulation is the establishment of the range of accuracy of the simulation.

Before describing specific tests, it is useful to distinguish between two types of predictive models. Within the class of predictive models there are two extremes which in pure form may be called application models and calculation tools. An application model is one based on well established laws and theories in which laws are applied to solve a particular problem. The usefulness of the model relates to the extent to which we have applied the laws correctly. In contrast, a calculation tool is a method for obtaining an answer which may not be based on any laws of nature at all. The classic example is a purely ad hoc model such as a multiple regression equation which may be biologically meaningless but can predict certain things to our satisfaction.

The two types of model are very different, not in the goodness of fit tests we can apply to test them but in the actions we take as a result of failure of the model (in some sense). For a calculation tool, most parts of the model are subject to adjustment. All sources of error are lumped into one error term in the model. We can change the structure, the form of the equations, and the parameters if it helps us to reduce the error. We can

iteratively run through the adjustment process until we (1) have a satisfactory model, (2) run out of time or money, or (3) test all possible models and find the "best" one.

In contrast, for an ideal application model, the only things subject to adjustment are the boundary conditions. When applying any law to a system it is necessary to decide on boundary conditions. We exclude factors that are of minor impact and decide that other factors are sufficiently exogenous to the system to be modelled as driving variables. Another type of boundary condition involves our methods of aggregation and representation. For example, we may aggregate all of the leaf biomass of a crop together and represent it's spatial pattern with some average vertical distribution. Even if we know the photosynthetic, light absorption and scattering, heat and vapor exchange, and other laws with a high degree of certitude (which we do not yet) it may still be very difficult to represent the crop canopy leaf distribution well enough to predict net primary production.

There are thus three sources of noise (besides measurement error) inherent in application type models: inherent noise (e.g., quantum phenomena, genetic variation within a population), boundary condition noise, and boundary condition aggregation and representation error. Inherent noise may be unavoidable or may be undetectable (though present). Thus, quantum effects at the atomic level cannot be eliminated by more accurate measurement but at the macroscale they may have no detectable effect. Similarly, genetic variation makes most biological processes inherently highly variable, though with a large enough sample size the variation may average out. Boundary condition noise results from the exclusion of some factor that is not truly insignificant. This may be eliminated by including the factor within the model or adding it as a driving variable. Boundary condition aggregation and representation error are not simple to eliminate and may require tremendous ingenuity on the part of the modeller, particularly in the case of ecosystems which are highly complex and heterogeneous in space.

The type of test applied for model evaluation should depend on the model type. For calculation tools, goodness of fit is a sufficient criteria but the way the data comparison is done depends on the type and complexity of the model. For application models, tests should not only evaluate goodness of fit but also show which of the three types of error is causing the lack of fit. If the noise is inherent we are wasting our time adjusting the aggregation scheme. If we treat an application model as though it was a calculation tool, feeling free to adjust all parts of it, then we are throwing away the information inherent in highly corroborated theories (laws). This is ad hocism, a very real danger for modellers.

Schwartzkopf (1980) describes a simple diagnostic validation method which both establishes the degree of confidence we may put in the results and provides a means of identifying the relative weaknesses and strengths of the model. As given, his method seems best suited to calculation tools but the same concept could be applied to application models if the three sources of error were kept in mind. The concept of selecting a model for use while simultaneously evaluating the input data is set forth in Shaeffer (1980). This approach can apply to both types of predictive models. While these concepts are useful, and the whole range of statistical tests must be considered, specific rules or procedures cannot be laid down because the

evaluation method used will depend too much on the type of model, project objectives, the nature of the data, etc. Thus, taking into account the above framework, the evaluation methods for the SAGEGRASS model will be specific to the nature of the problem.

5.3.3 Evaluation of SAGEGRASS

Model output should be used with great caution. It is not superfluous to reemphasize that all models are simplified abstractions of reality.

There are two general steps in interpreting model output for reasonability. The first of these is to compare the projected seasonal dynamics of state variables and flows to that of previous experience. Note, however, that each year is different. A check should be made to see if there is "internal consistency" in the dynamics of the different variables. For example, in the periods of time where the flow rate of standing live vegetation to standing dead vegetation is high, one should find a corresponding increase in the state variables for standing dead vegetation.

The second major way to interpret model output is not to rely on the result of one run, but instead to use several different runs. In general, it is desirable to impose a modelling experiment treatment in some quantitative scale. For example, different levels of rainfall should produce a specific kind of plot of production vs. rain. Designing such a model experiment requires specifying (i) the specific driving variable records to be used, (ii) the initial conditions, and (iii) the parameter values. It also requires determining which measures or output from the model run will be used in the evaluation.

In the SAGEGRASS model, anything from the literature that was based on well founded laws or accurately measured values was not subject to adjustment without specifying why this was done. Few such parameters were adjusted. To this extent it is an application model. Choices about aggregation and spatial relations relate to the boundary conditions of the application part of the model. Some relations, equations, and parameters were arbitrary or empirical and not necessarily biologically meaningful. For example, the manner in which factors were calculated to affect animal movement between ERUs was chosen so as to produce the desired dynamics without necessarily relating to the actual choices animals make. To this extent the SAGEGRASS model is a calculation tool.

A unique situation exists in ecological simulation. That is, parameters of species are correlated with environment due to local races. Therefore, it is hard to transport such a model or to test its credibility. Failure of a model tuned for Idaho climate to perform well in Colorado does not necessarily indicate failure of the model. Species parameters must be adjusted for local races in order to transport the model. Performance evaluation must be based on some other data set than an independent site test unless the site is nearby. Thus, for this model, tuning was done with the first four years of climate data and mainly with the first year (1963). Model performance can be tested against the next six years weather which was not used in model development.

The following sections evaluate SAGEGRASS performance in terms of the concepts domain and range and the sources of error discussed above.

5.3.3.1 Domain and Range of Abiotic Components

The domain of applicability of the abiotic section of the model is semi-arid vegetation climatic regimes. Very steep topography, extremely thin soils, sodic or saline soils, and flooded land cannot be handled by the model. Otherwise, normal weather in the sagebrush type of North American should be within the domain.

With minor exceptions, the abiotic sections may be considered to be an application model. Equations for heat exchange, percolation of water, etc. are fairly well known. The fact that the heat and soil water dynamics are reasonable over long simulation periods with no tuning of the model indicates the robustness of the laws used. However, the correctness of the application of boundary conditions to the Garat in particular cannot be checked because there are no data for comparison. What can be done is to state the possible souces of error encountered in defining the boundary conditions.

There is inherent error involved in measuring the climate variables and soil types, but this is overwhelmed by the other sources of error.

The boundary condition noise type of error results mainly from using climate data from Twin Falls, Idaho because no data was available on the Garat, and from having to estimate potential evaporation and wind in the winter. The magnitude of the effect caused by these is hard to guess at but is probably not large. Other sources of boundary condition error relate to soil and climate variables not included that might be significant. There is no way to estimate this at present.

The boundary condition aggregation error is probably the largest source of error for the overall model. The use of daily rather than more frequent values for climate variables, and the averaging of climate and soils over pastures many thousands of hectares in size is a clear example of the aggregation/representation problem. How can we be sure that the average soil we model along with the average climate will produce results that we can justify applying to the original heterogeneous pasture? Without field studies which may be used to statistically test equivalence of soil types, it is hard to answer this question.

5.3.3.2 Domain and Range of Flora Submodel

The domain of applicability of the flora submodel is the major species groups of the sagebrush-grass ecosystem. More specifically, the domain covers the modelled state variables of the components of these species groups as they vary during the year. Nothing can be said about factors not modelled such as lignin content.

Because no extensive data set could be found that could be used for either model development or model testing, the range of accuracy is hard to

establish. As in the abiotic model, what must be done at this point is to describe the sources of possible error.

Inherent noise exists in all sexual biological populations because of genetic variation. The significance of this noise depends on the process in question. Part of the variance around the mean for various features will represent this inherent noise.

Some of the relations in the plant submodel may be classified as being of the calculation tool type. These are subject to more arbitrary revisions, if necessary, to fit the data. However, major discrepancies should lead us to seek more biologically realistic functions. The basis for choosing model functions was Occam's Razor which was applied because a lack of good data precluded fitting parameters for complex functions or even for determining the nature of biologically realistic functions. Some error may be introduced by the use of these ad hoc equations.

Even if the ad hoc equations used are adequate representations of the individual processes, considerable boundary condition error is present.

Boundary condition error must be evaluated within the context of the model domain of applicability. There will always be rare diseases, pollution agents, etc. whose affect lies outside the intended domain. For the SAGEGRASS model, there are some potential boundary condition errors within the intended domain. One of these is that production is overestimated for high fertility and/or high precipitation conditions. This results from failure to include within the system boundaries the effects of self-shading and limiting nutrient availabilities. Another such error results from the failure to include the effects of temperature on basal respiration. Such errors reduce the realized domain or introduce biases in parts of the domain. The complete description of boundary condition errors within the context of project objectives awaits more extensive testing.

Several examples of aggregation and representation error may be cited. Old and young leaves as well as ephemerals, if present, are represented as one homogeneous category. Similarly, roots are represented as a uniform class. The soil is modelled in such a way that roots have equal and uniform access to all soil in a layer if there are any roots present at all. Spatial heterogeneity is ignored, preventing the modelling of species present only on special microsites.

In spite of all these sources of error, the model structure and equations appear robust enough to allow approximate seasonal dynamics of major species groups to be repreented.

5.3.3.3 Domain and Range of Fauna Submodel

The domain of the fauna model is the metabolism, population change, and spatial distribution of animals.

Whereas the metabolism equations are largely of the application model type, the diet, population change (birth, death, predation, maturation), and migration functions are largely to completely ad hoc (calculation tool type)

or empirical. Because the fauna model has not been as extensively tested as the other parts of the model, only brief examples of sources of error can be given.

Inherent error (noise) stems from genetic diversity and the same comments apply as with plants.

One example of boundary condition error involves animals that spend part of their life outside the spatial limits of the modelled pastures (birds, deer, coyotes, etc.) or belowground (grubs, gophers) where the diet selection algorithm is incapable of modelling root consumption. Similarly, the model does not allow consumption of plant juices by sapsucking insects.

Aggregation and representation errors relate to the fact that classes of species are modelled as one "specie." Other such errors appear in the diet selection process and habitat evaluation algorithm.

Overall, the fauna model seems fairly robust but the realized domain and range of accuracy are not well quantified. It should be noted that it has only been tested with mammals.

5.3.3.4 Domain and Range of SAGEGRASS, Summary

Before a detailed description of the overall domain and range of SAGEGRASS is undertaken, it is recommended that (1) obvious data deficiencies be remedied, (2) major shortcomings of the model be fixed (see Sec. 6.3), and (3) the model be tested on a site with adequate baseline data for comparison. Until these steps are taken only the sources of possible error and obvious model flaws can be described.

6. CONCLUSIONS AND GENERAL DISCUSSION

In this section we give some general conclusions about the modelling activity. We discuss some aspects of limitations of data and models, research needs, and give general strategies for use of the model. Particularly, we give a specific set of recommendations towards the completion of the development and use of this model structure for management planning.

In general, a model of this degree of complexity must be critiqued by many people and tested under many conditions in order to discover parameters and data which need refinement. This refinement can lead to vastly improved model performance.

6.1 Data Limitations

To formulate an ecosystem process in mathematical terms requires a rather precise understanding of the physical and physiological forces that together comprise the process. Often our knowledge of even the major processes is incomplete. The model is, therefore, based on the best, though partial, information available and, where data are lacking, on the most reasonable conceptualization of the process.

The model can be operated only by specifying driving variable records, initial conditions, and the parameters used in the flow functions. "Poor guesses" at initial conditions of state variables will not greatly affect model output. However, parameter values for the flow functions may be quite important. The question then is how "good" is the available data from which parameter values may be derived? It may be necesary to draw upon data for related groups of organisms to specify a specific species or group within the model. For example, if the model has a category of small mammals as a state variable, information may be available for related groups of small mammals from another region. These values could then be adapted to the small mammals in a given ecological response unit. For some parameter values there may be no data at all and model tuning and intuition are the only methods available for obtaining values.

Other errors are introduced by the process of deriving parameters from studies usually done for quite different purposes. Also, it is often necessary to treat parameters as time invariant even though they may be influenced by soil water, for example, in order to avoid modelling every minute aspect of physiology.

6.2 Model Limitations

All models are abstractions of real life. Therefore, some of the limitations are due to the process of simplification. The model is limited by general assumptions about the structure and function of the system being considered. It is limited in the present case particularly by the aggregation of plant and animal subsystems into ecological response units and the aggregation of system components into the selected state variables.

To be useful a model must be tractable. Even if complete data and com-

prehensive understanding of all the major ecosystem processes were available, because of the complexity of an ecosystem, sufficient computer storage and processing time would not be available to handle it. In addition, the more complete and precise the model representation, the more specific is the model to particular geographic races of plants and animals. A high degree of specificity is not desirable when the model is intended to indicate general responses of such systems or to extrapolate to some future and only partially known conditions.

Ecological Response Units are conceptual generalizations of the habitats, defined as a system that responds in some unique fashion to system activities. It is recognized that there is variability among the different components of an ERU and, therefore, the response of the ERU will be based primarily upon the responses of dominant plant and animal species selected as representative. The model output, therefore, represents a generalized response for that segment of habitat. It is essential to generalize in this fashion in order to make the model practical, although the actual responses of the system components may vary.

6.3 Research Needs

Once a simulation model has been tested, various improvements become obvious. Equations whose functional form is known with some confidence may be subjected to sensitivity analysis and parameter adjustment. For equations with a lower degree of functional form certainty more rigorous comparisons may be made against the literature or field experiments may be performed. Specific work needed is discussed below by submodel.

Climate. Model testing showed that because of nonexistent evaporation and wind data in midwinter, the prediction of solar radiation was not entirely satisfactory. This may be rectified by estimating solar radiation in another way or by obtaining better estimates for the missing data.

Abiotic. If no changes are made in the plant model which require soil temperature (see below), then there is currently no need for the heat submodel except for litter decomposition which could be based on air temperature. If the heat submodel is required in future versions of the model, then snow should act as an insulator and there should be heat exchange between the snow and the soil.

Flora. In order to use the respiration equation based on Thornly, the parameter KD (Barnes and Hole 1978) had to be reduced by an order of magnitude. This is most likely due to the fact that they derived it for plants at the peak of the growing season. It seems logical that maintenance respiration would vary with temperature. The error showed up via excessive winter respiration so KD was reduced to allow winter survival even though this meant an underestimate of summer respiration. It seems, then, that a better representation of basal respiration is needed to incorporate temperature effects. This may require basic research in plant physiology.

With the current checks in the models, the equations using XPALL may be redundant.

A fundamental problem in modelling terrestrial vegetation is the development of criteria for aggregating species. Minor plant species may occupy rare microsites. When thousands of hectares are aggregated and given one soil type, there is no way to model the competitive interactions mechanistically so that all species can be successfully modelled as occurring together. How do we decide which species to aggregate together? What parameters do we give to this "species?" For communities in which groups of species segregate based on microsite differences, an improvement in realism may be realized by adding a level to the spatial hierarchy. By modelling microsites within ERUs, each of which is considered to have a few dominants, the species diversity of a landscape may be considerably increased. The change in the fauna model which must accompany this is that animals in an ERU must be able to graze from all microsites within the ERU. This is essentially a bookkeeping problem that is technically tricky but not theoretically difficult.

It may be necessary at some future time to model sagebrush more realistically by incorporating ephemeral leaves into the model.

It is not sufficiently possible to distinguish between tap-rooted and fibrous rooted species in the model. The solution to this is not clear.

Because of the extreme genetic variability exhibited by cheatgrass, the modelling assumption of genetic uniformity breaks down. This heterogeneity is a significant aspect of the adaptive strategy of cheatgrass which enables it to survive suppression and then respond to site availability rapidly. Modelling such a process may require an entirely different model framework. Thus, cheatgrass as modelled is similar to cheatgrass but does not capture its strategy very well.

Fauna. Although the fauna submodel seems to function adequately, several areas could use improvement.

Many aspects of the diet selection and intake process need reworking. Because the animal has a constant diet by season for each ERU, change in species composition may give rise to plants being available which the animal cannot eat, although in reality it could. Also, animals are not able to distinguish between plant parts. Solving these problems would not be simple. There is a need for better allocation of grazing to green and nongreen vegetation. Coyotes need to be able to have access to carrion which is modelled but is inaccessible to them. The inability of animals to distinguish between shrub age classes means that all grazing of a shrub species is taken from the size class first encountered in the data structure. Thus, an attempt may be made to take a large amount of forage from a very few small shrubs, giving unrealistic results. This problem needs resolution. Because dead is as nutritious as green and because green is equally nutritious in all seasons, winter is not particularly severe and the lack of resulting mortality keeps fauna populations too high. Another problem is that juvenile and immature cohorts of most species are able to eat unreasonably large amounts of food. This is because they are able to eat whatever they need for respiration and growth if it is available. This should be contrained by realistic maximum intake rates.

A minor problem is that animals are able to migrate while hibernating. While the idea of somnambulant ground squirrels is amusing and no major problems result, it is somewhat unrealistic.

The home range concept is weak. What should be used is the area the animal could search by sight, smell, and hearing per day. It has been shown (Schoener 1968) that the area of the home range can be expressed as a function of body weight

$$A = kW^b$$

where k, b and parameters. This function should be used and computed for each size class, rather than being a constant parameter. The area searched and distance traveled per day would then be functions of this value.

There is no purpose served by the use of MAXLEANWT and it should be removed wherever it occurs.

The problems involved in aggregating species of plants apply generally to animals. How do we decide which species to aggregate? Two species of birds may be very similar morphologically and yet occupy different habitats. Once again, modelling simple systems and using biological intuition seem to be the only options available.

Other unsolved problems are of a spatial nature. Many spatial aspects of ecosystems are very hard to model. Some species may be limited by burrows or nesting sites. How can these be modelled? Many species cross in and out of any boundaries chosen by the modeller. Unless the area is extremely large, boundary crossing by birds, deer, etc. may be appreciable. How, then, do we model a deer herd during the part of the year when it leaves the area being modelled?

Another spatial problem relates to migration. The model does not take into account barriers (such as rivers) between ERUs, or the fact that one ERU may actually be small patches occurring scattered among other habitat types, thus being very accessible. In addition, the habitat selection algorithm seems unsatisfactory. Two identical ERUs with different area will not end up with identical population densities. A more behaviorally oriented algorithm, based on how animals make choices, would be attractive if it existed. However, to our knowledge, no such model has ever been developed.

Simulation. Some of the current technical issues needing further work include transportability, efficiency, verification, and documentation. All of these would improve the model.

Because there is no standard version of PASCAL, transportability of the model is limited. This tradeoff was felt to be worthwhile because of the need for data structuring capabilities found in PASCAL. In the future there will no doubt be a standard version of PASCAL and the model can be converted to it.

Model efficiency could be improved by thorough examination of the code. Many efficiency changes have already been made. Further improvements depend to a large degree on the user environment: whether storage space or execution time is more limiting. Until experience on the BLM computer has been gained the nature of such tradeoffs must remain speculative.

Verification of model code has been done but due to cost constraints has not been up to rigid computer science standards. A more thorough check of the code could be done.

At the last minute an error became apparent in the code, so that there was no time to trace it and fix it. The problem is isolated in the EVENT procedures so that most of what the model does is unaffected as long as events are not executed. What happens is that when an event is executed to put cattle onto an ERU, using the input files which gave the results described in this report, rainfall becomes zero. This suggests a data structure problem perhaps caused by incorrect creation and/or disposal of records. It is not clear if only procedure HERDDRIVE causes this error or if all event routines cause the problem. This problem needs tracing down if events are to be used.

Another minor problem is that the flora analysis program (INTERP) fails to find data values for total cover, total live cover, and total green so that when it reformats the data zeros are printed.

Further documentation of the model could be done. Much of this should be internal to the code: making variable names more self explanatory, aligning block structures better, adding comments, making variable type definitions in the data structure include information about units (grams, meters, etc.) and similar changes.

6.4 Strategies of Model Usage

Model output should be used with great caution. It is not superfluous to reemphasize that all models are simplified abstractions of reality.

One strategy in making model experiments is as follows. A standard summary of simulation statistics is printed including the date of the simulation, initial simulation time, terminal simulation time, and the time steps used by the different submodels. It also specifies the different ecological esponse units incorporated, the specific driving variable set used and a definition of the model version. A specific table is developed which lists the state variables and their initial conditions. Another table lists the flows and the parameter values used in each flow calculation.

Outputs are summarized in several tabular and graphic ways. Standard tables are made for state variables, flows, intermediate variables, and output variables. These tables list each of the items by name and give their values at selected intervals. Simple descriptive statistics are calculated including the mean, standard deviation, sample size, and maximum and minimum values. The number of times each flow was greater than zero is also specified.

Standard graphs are made of the state variables, flows, output variables, and driving variables. Each graph plots the item against time. The graphs are done in such a way that they are readily reducible for use in reports and publications.

There should be a continued improvement of information regarding the structure, parameterization, and outputs of the model. Revising such a model periodically should be a standard part of agency procedure, as it is in the

Forest Service with respect to timber management models. Furthermore, periodic sensitivity analyses, both qualitative and quantitative, should be made of the model to derive information regarding research needs.

6.5 Some Specific Recommendations Regarding Model Development and Usage

The development of a model such as SAGEGRASS is of little use if it is not used by the sponsoring agency, the BLM in this case. Minimum requirements for this to occur include training workshops, detailed training of one or more scientists responsible for troubleshooting during uses of the model at the district level, incorporation of the modelling approach into standard agency planning procedures, and periodic improvements of the model as knowledge increases.

The SAGEGRASS model has significant potential for augmenting standard BLM planning procedures. The model may be used to generate many alternatives in the environmental impact evaluation process. This allows the comparison of multiple alternatives without excessive expense. More importantly, it allows the organization of information in a systematic way and projections are based on well documented biological assumptions. The limitations of the model do not allow evaluation of more species or of sites with a paucity of data, so the model cannot answer all impact questions.

After the impact analysis, the model may be used for continuing on-the-ground planning of grazing plans and range improvement practices.

Workshops should be held to acquaint managers and scientists in each district with what the model can do and how it works. It should be emphasized that such workshops will not be greeted with enthusiasm unless the managers see that the model fits into the planning process as defined in official agency guidelines and unless upper level officials support its use.

The final requirement for successful use of the model is adequate technical support. Someone at the BLM needs to be familiar enough with the model and with computers to assist persons who wish to use it. Problems which are simple to someone familiar with the model may be completely insoluble to a novice. For example, confusing the order of input of data may give bizarre results without ever causing an overt error. It is estimated that someone could become familiar with the model in from one to three months, depending on their background. Such a training period should include reading this report, learning PASCAL briefly, reading the computer code, making practice runs, and creating intentional data errors to discover what happens. Once the program and data files are set up by someone with detailed knowledge, managers could use the model to test particular management schemes without too much difficulty.

7. LITERATURE CITED

Anderson, A. E., D. E. Medin, and D. C. Bowden. 1974. Growth and morphometry of the carcass, selected bones, organs, and glands of mule deer. Wildlife Mono. No. 39.

Ares, J., and J. S. Singh. 1974. A model of the root biomass dynamics of a shortgrass prairie dominated by blue grama (Bouteloua gracilis). J. Appl. Ecol. 11:727-744.

Barnes, A. and C. C. Hole. 1978. A theoretical basis of growth and maintenance respiration. Ann. Bot. 42:1217-1221

Blaisdell, J. P. 1949. Competition between sagebrush seedlings and reseeded grasses. Ecology 30:512-519.

Blaisdell, J. P. 1958. Seasonal development and yield of native plants on the upper Snake River Plains and their relation to certain climatic factors. USDA Tech. Bull. 1190. 68 pp.

Botkin, D. B. 1977. A functional approach to the niche concept in forest communities, p. 149-158. In G. S. Innis (ed.). New directions in the analysis of ecological systems. Part 2.

Brody, S. 1945. Bioenergetics and growth. Reinhold Publ. Co., New York. 1023pp.

Brown, R. W. 1971. Distribution of plant communities in southeastern Montana Badlands. American Midland Nautralist 85(2):458-477.

Burge, J. R., and C. D. Jorgensen. 1973. Home range of small mammals: A reliable estimate. J. of Mammalogy 54:483-488.

Bureau of Land Management. 1980. Information gathered from BLM staff during workshops at Boise, Idaho.

Buwai, M. and M. J. Trlica. 1977. Defoliation effects on root weights and total nonstructural carbohydrates of blue grama and western wheatgrass. Crop Science 17:15-17.

Cale, W. G. Jr., and P. L. Odell. 1979. Concerning aggregation in ecosystem modeling, pp. 55-77. IN E. Halfon (ed.). Theoretical systems ecology. Academic Press, New York. 516 pp.

Capiel, M. 1970. Estimating solar radiation intensity from other meteorological data. J. of Agriculture of University of Puerto Rico. p377-389.

Caswell, H. 1976. The validation problem, p. 313-325. In B. C. Patten (ed.). Systems analysis and simulation in ecology. Vol. IV. Academic Press, NY.

Christensen, E. M., and S. F. Welsh. 1963. Presettlement vegetation of the valleys of western Summit and Wasatch counties, Utah. Proc. Utah Acad. of Sciences, Arts, and Letters. Part II. 40:163-174.

Cole, G. W. (ed.). 1976. ELM: version 2.0. Range Sci. Dept., Sci. Series No. 20, Colorado State Univ., Fort Collins. 663pp.

Cook, C. W., L. A. Stoddard, and I. A. Phillips. 1967. Effects of season, spacing, and intensity of seeding on the development of foothill range grass stand. Utah Agric. Exp. Sta. Utah State Univ. Bull. 467.

Cook, C. W. 1971. Effects of season and intensity of use on desert vegetation. Utah Agric. Exp. Sta. Utah State Univ. Bull. 483.

Couturier, D. E., and E. A. Ripley. 1973. Rainfall interception in mixed grass prairie. Can. J. Plant. Sci. 53:659-663.

Cutler, M. M. 1980. Validation proofs of discrete event simulation programs. Summer Computer Simulation Conference. p.240-245.

Daubenmire, R. 1980. Mountain topography and vegetation patterns. Northwest Science 54:146-152.

Davey, J. R. 1980. Energy flow dynamics of a desert grassland ecosystem. Ph.D. dissertation, Northern Arizona State University, Flagstaff, AZ.

de Vries, D. A., and N. H. Afgan (eds.). 1975. Heat and Mass transfer in the biosphere: Part 1, Transfer processes in the plant environment. Scripta Book Co., Washington, D. C. 591pp.

DePuit, E. J., and M. M. Caldwell. 1973. Seasonal pattern of net photosynthesis of artemisia tridentata. Amer. J. Bot. 60:426-435.

DePuit, E. J., and M. M. Caldwell. 1975. Stem and leaf gas exchange of two arid land shrubs. Amer. J. of Botany 62:954:961.

Detling, J. K., and W. J. Parton. 1978. Primary producer submodel. In Ellis, J. E., and W. J. Parton (eds.). Impact of strip-mine reclamation practices: A simulation study. Nat. Res. Ecol. Lab., Colorado State Univ., Fort Collins.

Dina, S. J., and L. G. Klikoff. 1973. Effect of plant moisture stress on carbohydrate and nitrogen content of big sagebrush. J. of Range Manage. 26:207-209.

Dougal, M. D. 1971. Snowmelt analysis in the Midwest and its role in water runoff management. In Haugen, H. O. (ed.). Proceedings of the Snow and Ice in Relation to Wildlife and Recreation Symposium, Iowa Coop. Wildlife Research Unit, Univ. of Iowa, Ames. 281pp.

Frischknecht, N. C., and L. E. Harris. 1968. Grazing intensities and systems on crested wheatgrass in central Utah: Response of vegetation and cattle. USDA Forest Service Tech. Bull. 1388.

Gilbert, P. F., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. J. of Wildl. Manage. 34:15-23.

Golley, F. B. 1961. Energy values of ecological materials. Ecology 42:581-583.

Gordon, K. 1943. The natural history and behavior of the western chipmunk and the mantled ground squirrel. The College Press. Oregon State College, Corvallis, Oregon.

Grime. J. P. 1979. Plant strategies and vegetation processes. John Wiley & Sons. 222 pp.

Guardado, J. L., and W. T. Sommers. 1977. Interpolation of unevenly spaced data using a parabolic leapfrog correction method and cubic splines. U.S.D.A. Forest Service Res. Note PSW-324. 5pp.

Halin, H. J., R. Buhrer, W. Halg, H. Benz, B. Bron, H. J. Brundiers, A. Isacson, and M. Tadian. 1980. The ETH multiprocessor project: Parallel simulation of continuous systems. Simulation October:109-123.

Hamilton, W. J., Jr. 1939. American mammals, their lives, habits, and economic relations. McGraw-Hill Book Co., Inc., New York.

Harris, G. A. 1967. Some competitive relationships between Agropyron spicatum and Bromus tectorum. Ecol. Mono. 37:89-111.

Hedrick D. W., D. N. Hyder, and F. A. Sneva. 1964. Overstory-understory grass seedings on sagebrush-burch grass range. Oregon State University Agric. Expt. Station Tech. Bull. 80.

Hedrick, D. W., D. N. Hyder, F. A. Sneva, and C. E. Poulton. 1966. Ecological response of sagebrush-grass range in central Oregon to mechanical and chemical removal of Artemisia. Ecology 47(3):432-439.

Herreid, C. F., and B. Kessel. 1967. Thermal conductance in birds and mammals. Comp. Biochm. Physiol. 21:405-414.

Hillel, D. 1977. Computer simulation of soil-water dynamics. International Developmental Research Center, Hawaii. 214pp.

Humphreys, W. F. 1979. Production and respiration in animal populations. J. of Anim. Ecol. 48:427-453.

Hyder, D. N., and F. A. Sneva. 1963. Studies of six grasses seeded on sagebrush-bunchgrass range - Yield, palatability, carbohydrates accumulation and developmental morphology. Oregon Agric. Expt. Station Tech. Bull. 71.

Innis, G. S., S. Schlesinger, and R. J. Sylvester. 1977. Model certification - varying views from different specialties, p. 695-699. In Summer Computer Simulation Conference Proceedings.

Jackson, R. D. 1972. On the calculation of hydraulic conductivity. Soil Sci. Soc. Amer. Proc. 36:380-382.

Johnson, D. R. 1961. The food habits of rodents on rangelands of southern Idaho. Ecology 42:407-410.

Jump, R. C., C. S. Loehle, G. M. Van Dyne, L. D. Watson, J. Davey, N. R. French, and J. W. Skiles. 1980. A.E.S.O.P. An ecosystem simulation of perturbations applied to shale oil development. November 1980 report to the Department of Energy, Washington, D.C.

Kendeigh, S. C. 1969. Tolerance of cold and Bergmann's Rule. The Auk 86:13–25.

Kendeigh, S. C. 1970. Energy requirements of existence in relation to size of bird. The Condor 72:60–65.

Kohler, M. A., T. J. Nordenson, and W. E. Fox. 1955. Evaporation from ponds and lakes. Research Paper No. 38. Weather Bureau, U.S. Dept. of Commerce. Washington, D.C. 21pp.

Larcher, W. 1975. Physiological plant ecology. Springer-Verlag, New York. 252pp.

Lasiewski, R. C., and W. R. Dawson. 1967. A re-examination of the relation between standard metabolic rate and body weight in birds. The Condor 69:13–23.

Lee, C. 1973. Models in planning. Pergamon Press, New York. 209pp.

Loehle, C., and G. M. Van Dyne. 1979. A bibliography of sagebrush--grass grazingland ecosystems indexed for information for simulation model development. Progress report December 1979, Range Science Dept., Colorado State Univ., Fort Collins. 55pp.

Loehle, C., and G. M. Van Dyne. 1979. SAGE: A sagebrush--grass grazingland ecosystem model. Progress report June, 1979. Range Science Dept., Colorado State Univ., Fort Collins. 189pp

Loehle, C., R. C. Jump, and G. M. Van Dyne. 1980. SAGE: A sagebrush--grass grazingland ecosystem simulation model. Progress report January 1980. Range Science Dept, Colorado State Univ., Fort Collins. 104pp.

Mankin, J. B., R. V. O'Neill, H. H. Shuggart, and B. W. Rust. 1975. The importance of validation in ecosystem analysis, p. 63–71. In G. S. Innis (ed.). New directions in the analysis of ecological systems. Part I. Sim. Council, La Jolla, CA.

Marshall, J. K. (ed.). 1977. The belowground ecosystem: A synthesis of plant associated processes. Range Sci. Dept., Sci. Ser. No. 2., Colorado State Univ., Fort Collins. 352pp.

Masterson, W. L., and E. J. Slowinski. 1969. Chemical principles. W. B. Saunders Co., Philadelphia. 705pp.

McCree, K. F., J. H. Troughton. 1966. Non-existence of an optimum leaf area index for the production rate of white clover grown under constant conditions. In Plant Phys. 41:1615–1622.

McGill, W. B., H. W. Hunt, R. G. Woodmansee, and J. O. Reuss. 1981. PHOENIX: A model of the dynamics of carbon and nitrogen in grassland soils. In E. E. Clark and T. Rosswall (eds.). Nitrogen cycling in terrestrial ecosystems. Ecol. Bull., Stockholm. (In press).

McIvanie, S. K. 1942. Carbohydrate and nitrogen trends in bluebunch wheatgrass, Agropyron Spicatum, with special reference to grazing influences. Plant Physiology 17:540-557.

McNab, B. K. 1970. Body weight and the energetics of temperature regulation. J. Exp. Biol. 53:329-348.

McNab, B. K. 1979. The influence of body size on the energetics and distribution of fossorial and burrowing mammals. Ecol. 60:1010-1021.

Meeuwig, R. O., E. L. Miller, and J. D. Budy. 1979. Estimating Pinyon and Juniper fuel and biomass from aerial photographs. USDA Forest Service, Res. Note INT-274.

Morris, D. 1965. The mammals, a guide to the living species. Harper and Row, New York. 182pp.

Milchunas, D. G., M. I. Dyer, O. C. Wallmo, and D. E. Johnson. 1978. In-vivo/in-vitro relationships of Colorado mule deer forages. Colorado Div. of Wildl. Spec. Rep. 43.

Nagy, J. G. 1978. Wildlife nutrition and the sagebrush ecosystem. IN The sagebrush ecosystem: A symposium. Utah State University, College of Natural Resources, Logan. 251 pp.

Nagy, J. G., D. L. Baker, J. A. Bailey, D. S. de Calesta, D. E. Reeder, and G. G. Schoonveld. 1974. Middle Park cooperative deer study. Physiology and prevention of deer starvation. Colorado Div. Wildl. Fed. Aid Project W-38-R-28. Final Rep. 554pp.

Nielson, D. B., and S. B. Hinckley. 1975. Economic and enviornmental impacts of sagebrush control on Utah's rangelands - A review and analysis. Utah State University Agric. Expt. Station Research Rpt. 25.

Orians, G. H., and O. T. Solbrig. 1977. A cost-income model of leaves and roots with special reference to arid and semiarid areas. American Naturalist 111:667-690.

Perez-Trejo, F., D. D. Dwyer, and K. H. Asay. 1979. Forage yield, phenological development, and forage quality of an Agropyron repens X A. spicatum hybrid. J. of Range Manage. 32:387-390.

Platt, J. R. 1964. Strong inference. Sci. 146:347-353.

Popper, K. R. 1965. Conjectures and refutations. Harper & Row, NY. 417 pp.

Reece, P. E. 1974. Autecology of three perennial grasses relative to microenvironmental modification following permanent defoliation of Wyoming big sagebrush. Ms. Thesis, Oregon State University. 136pp.

Ricklefs, R. E. 1967. Patterns of growth in birds. Ibis 110:419-451.

Rittenhouse, L. R., and F. A. Sneva. 1977. A technique for estimating big sagebrush production. J. Range Manage. 30:68-70.

Robertson, J. H. 1947. Responses of range grasses to different intensities of competition with sagebrush (Artemitia tridentata Nutt.). Ecology 28(1):1-16.

Robinette, W. L., and J. S. Gashwiler. 1955. Fertility of mule deer in Utah. J. Wildl. Manage. 19:115-136.

Rue, L., III. 1978. The deer of North America. Crown Publishers, Inc., New York. 122pp.

Sauer, R. H., and R. W. Uresk. 1976. Phenology of steppe plants in wet and dry years. Northwest Science 50:133-139.

Schoener, T. W. 1968. Sizes of feeding territories among birds. Ecology 49:123-141.

Schwartzkopf, S. H. 1980. An elementary method for the diagnosic validation of simulation models, p. 236-239. In Summer Computer Simulation Conference Proceedings.

Shaeffer, D. L. 1980. A model evaluation methodology applicable to environmental assessment models. Ecological Modeling 8:275-295.

Siler, W. 1979. A competing-risk model for animal mortality. Ecol. 60:750-757.

Stearnes, G. 1959. Oregon sunshine. Weekly weather bulletin national summary, Vol. XLVI, No. 25, p6-8.

Stoddart, L. A. 1946. Some physical and chemical responses of Agropyron spicatum to herbage removal at various seasons. Ag. Exp. Sta., Utah State Ag. Coll. Bull. 324. 24 pp.

Sturges, D. L. 1977. Soil water withdrawal and root characteristics of big sagebrush. Amer. Midland Nat. 98:257-274.

Tanner, J. T. 1966. Effects of population density on growth rates of animal populations. Ecol. 47:733-745.

Taylor, W. P. 1956. The deer of North America. Wildlife Management Institute. Washington, D.C. 479pp.

Templeton, A. R., and L. R. Lawlor. 1981. The fallacy of the averages in ecological optimization theory. Am. Nat. 117:390-393.

Thornley, J. H. M. 1976. Mathematical models in plant physiology. Academic Press, NY. 318pp.

Thornley, J. H. M. 1970. Growth, maintenance and respiration: a re-interpretation. Ann. Bot. 41:1191-1203.

Tueller, P. T., C. D. Beeson, R. J. Tausch, N. E. West, and K. H. Rea. 1979. Pinyon-Juniper Woodlands of the Great Basin: Distribution, flora, vegetal cover. USDA Forest Service, Res. Paper INT-229.

U.S. Forest service. 1968. Rainfall interception by annual grass and chaparral... losses compared. U.S.D.A. Forest Service Research Paper PSW-48. Pacific Southwest Forest and Range Exp. Sta., Berkeley, California. 12pp.

Van Dyne, G. M., and C. Loehle. 1979. Allotment scale simulation of sagebrush--grass grazingland for management planning. Progress report January 1979. Range Science Dept., Colrado State Univ., Fort Collins. 80pp.

Van Wijk, W. R. 1963. Physics of plant environment. North-Holland Publishing Co., Amsterdam. 382pp.

Van Wormer, J. 1964. The world of the coyote. J. B. Lippencott Co., New York.

Vass, A. F., and R. Lang. 1938. Vegetative composition density, grazing capacity and grazing land values in the Red Desert area. Wyoming Agric. Expt. Station Bull. 229.

Watt, K. E. 1968. Ecology and resource management. McGraw-Hill Book Co., New York. 450pp.

Wunder, B. A. 1975. A model for estimating metabolic rate of active or resting mammals. J. Theor. Biol. 49:345-354.

Wymore, I. F. 1974. Water requirements for stabilization of spent shale. Colorado State Univ., Fort Collins. Ph.D. dissertation. 137pp.

Zar, J. H. 1968. Standard metabolism comparisons between orders of birds. Condor 70:278.

Zinke, P. J. 1967. Forest interception studies in the United States, p137-161. In Sopper, W. E., and H. W. Ludd (eds.). Forest Hydrology. Pergamon Press, NY.

APPENDIX I -- Parameter Tables

Table 8.1. Parameter values for driving variables.

STANDARD NOTATION	VALUE	REFERENCE
P(C,1)	1.00	BLM Boise District (1980)
P(C,2)	0.00	BLM Boise District (1980)
P(C,3)	1.00	BLM Boise District (1980)
P(C,4)	0.00070588	BLM Boise District (1980)
P(C,5)	1.155	Capiel (1970)
P(C,6)	-0.015	Capiel (1970)
P(C,7)	-0.086	Capiel (1970)
P(C,8)	5.755	Capiel (1970)

Table 8.2. Parameter values for soil temperature submodel.

STANDARD NOTATION	VALUE	REFERENCE
- Sand -		
P(1,1)	2.73	Arbitrarily assigned
P(1,2)	0.180	Arbitrarily assigned
- Siltsand -		
P(1,1)	2.70	Van Wijk (1963)
P(1,2)	0.176	Van Wijk (1963)
- Sandclay -		
P(1,1)	2.76	Van Wijk (1963)
P(1,2)	0.197	Van Wijk (1963)
- Clay -		
P(1,1)	2.83	Arbitrarily assigned
P(1,2)	0.210	Arbitrarily assigned
- Claysilt -		
P(1,1)	2.79	Arbitrarily assigned
P(1,2)	0.180	Arbitrarily assigned
- Silt -		
P(1,1)	2.65	Van Wijk (1963)
P(1,2)	0.164	Van Wijk (1963)
P(1,3)	7.3	Arbitrarily assigned
P(1,4)	85.0	Van Wijk (1963)
P(1,5)	20.0	Larcher (1975)
P(1,6)	4.65	Van Wijk (1963)
P(1,7)	0.60	Van Wijk (1963)
P(1,8)	1.42	Van Wijk (1963)
P(1,9)		
P(1,10)	1.664E-7	Van Wijk (1963)
P(1,11)	596.0	Masterton (1969)

Table 8.2. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
P(1,12)	-0.56	Masterton (1969)
P(1,13)	273.0	Masterton (1969)
P(1,14)	1.0	Van Wijk (1963)
P(1,15)	1.0	Van Wijk (1963)
P(1,16)	0.46	Van Wijk (1963)
P(1,17)	4.0	Arbitrarily assigned

Table 8.3. Parameter values for soil water submodel.

STANDARD NOTATION	VALUE	REFERENCE
- Sand -		
P(2,1)	5.6E-4	Van Wijk (1963)
P(2,2)	31.0	Cole (1976)
P(2,3)	25.0	Cole (1976)
P(2,4)	15.0	Cole (1976)
P(2,5)	10.0	Cole (1976)
- Siltsand -		
P(2,1)	8.3E-6	Van Wijk (1963)
P(2,2)	22.0	Cole (1976)
P(2,3)	18.0	Cole (1976)
P(2,4)	12.0	Cole (1976)
P(2,5)	7.0	Cole (1976)
- Sandclay -		
P(2,1)	8.3E-8	Van Wijk (1963)
P(2,2)	36.0	Cole (1976)
P(2,3)	29.0	Cole (1976)
P(2,4)	18.0	Cole (1976)
P(2,5)	12.0	Cole (1976)
- Clay -		
P(2,1)	1.4E-9	Van Wijk (1963)
P(2,2)	36.0	Cole (1976)
P(2,3)	32.0	Cole (1976)
P(2,4)	18.0	Cole (1976)
P(2,5)	13.0	Cole (1976)
- Claysilt -		
P(2,1)	2.8E-8	Van Wijk (1963)
P(2,2)	36.0	Cole (1976)
P(2,3)	25.0	Cole (1976)
P(2,4)	18.0	Cole (1976)
P(2,5)	13.0	Cole (1976)

Table 8.3. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Silt -		
P(2,1)	1.7E-8	Van Wijk (1963)
P(2,2)	19.0	Cole (1976)
P(2,3)	16.0	Cole (1976)
P(2,4)	10.0	Cole (1976)
P(2,5)	6.0	Cole (1976)
- Trees -		
P(2,6)	11.0	Zinke (1967), USFS (1968)
P(2,7)	1.0	Zinke (1967), USFS (1968)
- Shrubs -		
P(2,6)	6.2	Zinke (1967), USFS (1968)
P(2,7)	8.3	Zinke (1967), USFS (1968)
- Forbs -		
P(2,6)	8.9	Zinke (1967), USFS (1968)
P(2,7)	11.5	Zinke (1967), USFS (1968)
- Grass -		
P(2,6)	3.2	Zinke (1967), USFS (1968)
P(2,7)	7.4	Zinke (1967), USFS (1968)
-Litter -		
P(2,6)	1.5	Zinke (1967), USFS (1968)
P(2,7)	2.5	Zinke (1967), USFS (1968)
P(2,8)	3.5	Arbitrarily assigned
P(2,9)	0.108	Dougal (1971)
P(2,10)	0.0	Dougal (1971)
P(2,11)	0.0	Arbitrarily assigned
P(2,12)	3.0	Arbitrarily assigned
P(2,13)	25.4	Dougal (1971)
P(2,14)	2.5	Arbitrarily assigned

Table 8.4a. Parameter values for Juniperus osteosperma.

STANDARD NOTATION	VALUE	REFERENCE
P(5,1)	100.0	Tueller et al. (1979)
P(5,2)	25.0	Tueller et al. (1979)
P(5,3)	0.000274	See text
P(5,4)	2770.0	Meeuwig et al. (1979)
P(5,5)	0.25	Meeuwig et al. (1979)
P(5,6)	0.07675*	Model tuning
P(5,7)	-30.0	First estimate

*Equal to zero on input, computed internally.

Table 8.4b. Parameter values for Pinus edulis.

STANDARD NOTATION	VALUE	REFERENCE
P(5,1)	100.0	Tueller et al. (1979)
P(5,2)	25.0	Tueller et al. (1979)
P(5,3)	0.000274	See text
P(5,4)	2150.0	Meeuwig et al. (1979)
P(5,5)	0.25	Meeuwig et al. (1979)
P(5,6)	0.07675*	Model tuning
P(5,7)	-30.0	First estimate

*Equal to zero on input, computed internally.

Table 8.4c. Parameter values for Agropyron sp.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	1.0	Model tuning
P(3,2)	0.01	Model tuning
P(3,3)	0.75	Model tuning
P(3,4)	0.07675*	Model tuning
P(3,5)	0.1	Model tuning
P(3,6)	0.1	Model tuning
P(3,7)	0.0355	Barnes and Hole (1978), model tuning
P(3,8)	1.0	Harris (1967), modified for site conditions
P(3,9)	0.06	Redman (1974)
P(3,10)	-28.0	Rittenhouse based on Reece (1974)
P(3,11)	1.5	Model tuning
P(3,12)	0.25	Buwai and Trlica (1977), McIlvanie (1942) and model tuning
P(3,13)	0.12	Model tuning
P(3,14)	3.0	Cole (1976)
P(3,15)	45.0	Cole (1976)
P(3,16)	26.0	Cole (1976)
P(3,17)	0.001	Model tuning
P(3,18)	0.5	Marshall (1977)
P(3,19)	-25.0	Trlica (personal communication), model tuning
P(3,20)	0.00013	Model tuning
P(3,21)	0.00333	McCree and Troughton (1966) (see text)
P(3,22)	0.755	DePuit and Caldwell (1975)
P(3,23)	0.01	Model tuning
P(3,24)	-30.0	Cole (1976)
P(3,25)	0.7	Model tuning
P(3,26)	0.0	Model tuning
P(3,27)	8.0	Model tuning

Table 8.4c. (continued)

STANDARD NOTATION	VALUE	REFERENCE
-Winter-		
P(3,28)	0.078	Perez-Trejo et al. (1979)
-Spring-		
P(3,28)	0.13585	Perez-Trejo et al. (1979)
-Summer-		
P(3,28)	0.078	Perez-Trejo et al. (1979)
-Autumn-		
P(3,28)	0.11378	Perez-Trejo et al. (1979)
-Winter-		
P(3,29)	0.0432	McGill et al. (In press)
-Spring-		
P(3,29)	0.0432	McGill et al. (In press)
-Summer-		
P(3,29)	0.0432	McGill et al. (In press)
-Autumn-		
P(3,29)	0.0432	McGill et al. (In press)

*Equal to zero on input, computed internally.

Table 8.4d. Parameter values for Bromus tectorum.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	1.0	Model tuning
P(3,2)	0.01	Model tuning
P(3,3)	0.75	Model tuning
P(3,4)	0.09210*	Model tuning
P(3,5)	0.1	Model tuning
P(3,6)	0.1	Model tuning
P(3,7)	0.0355	Barnes and Hole (1978), model tuning
P(3,8)	1.2	Harris (1967)
P(3,9)	0.08	Higher than Agropyron
P(3,10)	-25.0	Less than Agropyron
P(3,11)	1.5	Model tuning
P(3,12)	0.25	Model tuning
P(3,13)	0.12	Same as Agropyron
P(3,14)	0.0	Cole (1976)
P(3,15)	40.0	Cole (1976)
P(3,16)	20.0	Cole (1976)
P(3,17)	0.001	Model tuning
P(3,18)	0.5	Marshall (1977)
P(3,19)	-25.0	Trlica (personal communication), model tuning
P(3,20)	0.00013	Model tuning
P(3,21)	0.00333	McCree and Troughton (1966) (see text)
P(3,22)	0.755	DePuit and Caldwell (1975)
P(3,23)	0.012	Model tuning
P(3,24)	-25.0	Cole (1976)
P(3,25)	0.000233	Same as Agropyron
P(3,26)	-15.0	Model tuning
P(3,27)	8.0	Model tuning
P(3,28)	(See Agropyron)	Same as Agropyron
P(3,29)	(See Agropyron)	Same as Agropyron

*Equal to zero on input, computed internally.

Table 8.4e. Parameter values for Artemesia tridentata.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	1.0	Model tuning
P(3,2)	0.01	Model tuning
P(3,3)	0.75	Model tuning
P(3,4)	0.05756*	Model tuning
P(3,5)	0.1	Model tuning
P(3,6)	0.1	Model tuning
P(3,7)	0.0355	Barnes and Hole (1978), model tuning
P(3,8)	1.8	Sturges (1977)
P(3,9)	0.045	DePuit and Caldwell (1973)
P(3,10)	-60.0	Rittenhouse based on Reece (1974)
P(3,11)	1.5	Model tuning
P(3,12)	0.10	Model tuning
P(3,13)	0.08	Dina and Klikoff (1973)
P(3,14)	8.0	Cole (1976)
P(3,15)	45.0	Cole (1976)
P(3,16)	35.0	Cole (1976)
P(3,17)	N.A.	---
P(3,18)	0.5	Marshall (1977)
P(3,19)	-30.0	Trlica (personal communication), model tuning
P(3,20)	0.0001	Model tuning
P(3,21)	0.00333	McCree and Troughton (1966) (see text)
P(3,22)	0.943	DePuit and Caldwell (1975)
P(3,23)	N.A.	---
P(3,24)	-30.0	Cole (1976)
P(3,25)	0.000233	DePuit and Caldwell (1975)
P(3,26)	-20.0	Model tuning
P(3,27)	21.5	Model tuning
-Winter-		
P(3,28)	0.06422	McGill et al. (In press), Nagy (1978)

Table 8.4e. (continued)

STANDARD NOTATION	VALUE	REFERENCE
-Spring-		
P(3,28)	0.06422	McGill et al. (In press), Nagy (1978)
-Summer-		
P(3,28)	0.06422	McGill et al. (In press), Nagy (1978)
-Autumn-		
P(3,28)	0.06422	McGill et al. (In press), Nagy (1978)
-Winter-		
P(3,29)	0.00432	McGill et al. (In press), Nagy (1978)
-Spring-		
P(3,29)	0.00432	McGill et al. (In press), Nagy (1978)
-Summer-		
P(3,29)	0.00432	McGill et al. (In press), Nagy (1978)
-Autumn-		
P(3,29)	0.00432	McGill et al. (In press), Nagy (1978)
P(4,1)	0	Not used
P(4,2)	0.002	Arbitrary
P(4,3)	-0.024	McCree and Troughton (1966)
P(4,4)	0.5	By definition
P(4,5)	300.0	Based on general phenology
P(4,6)	0.0005	Model tuning
P(4,7)	1.0	Arbitrary
-Winter-		
P(4,28)	0.003672	McGill et al. (In press), Nagy (1978)
-Spring-		
P(4,28)	0.003672	McGill et al. (In press), Nagy (1978)
-Summer-		
P(4,28)	0.003672	McGill et al. (In press), Nagy (1978)
-Autumn-		
P(4,28)	0.003672	McGill et al. (In press), Nagy (1978)

*Equal to zero on input, computed internally.

Table 8.4f. Parameter values for forbs.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	1.0	Model tuning
P(3,2)	0.01	Model tuning
P(3,3)	0.75	Model tuning
P(3,4)	0.06579*	Model tuning
P(3,5)	0.1	Model tuning
P(3,6)	0.1	Model tuning
P(3,7)	0.0355	Barnes and Hole (1978), model tuning
P(3,8)	1.2	Same value as Agropyron
P(3,9)	0.04	Same value as Agropyron
P(3,10)	-28.0	More than Agropyron
P(3,11)	1.5	Model tuning
P(3,12)	0.25	Model tuning
P(3,13)	0.12	Same as Agropyron
P(3,14)	0.0	Cole (1976)
P(3,15)	40.0	Cole (1976)
P(3,16)	20.0	Cole (1976)
P(3,17)	0.001	Model tuning
P(3,18)	0.5	Marshall (1977)
P(3,19)	-28.0	Trlica (personal communication), model tuning
P(3,20)	0.00013	Model tuning
P(3,21)	0.00333	McCree and Troughton (1966) (see text)
P(3,22)	0.755	DePuit and Caldwell (1975)
P(3,23)	0.012	Model tuning
P(3,24)	-30.0	Cole (1976), Blaisdell (1958) (estimate)
P(3,25)	0.000233	Same as Agropyron
P(3,26)	-10.0	Model tuning
P(3,27)	8.0	Model tuning
P(3,28)	(See Agroypron)	Same as Agropyron
P(3,29)	(See Agropyron)	Same as Agropyron

*Equal to zero on input, computed internally.

Table 8.5. Parameter values for litter.

STANDARD NOTATION	VALUE	REFERENCE
P(6,1)	-30.0	Cole (1976)
P(6,2)	0.0417	Model tuning
P(6,3)	0.0007	Model tuning

Table 8.6a. Parameter values for fauna biomass submodel.

STANDARD NOTATION	VALUE	REFERENCE
- Mammalia -		
P(8,1)	1.22	Wunder (1975)
P(8,2)	3.8	Wunder (1975)
P(8,3)	-0.25	Wunder (1975)
P(8,4)	4.91	Wunder (1975)
P(8,5)	-0.505	Wunder (1975)
P(8,6)	4.0	Wunder (1975)
P(8,7)	0.25	Wunder (1975)
P(8,8)	8.46	Wunder (1975)
P(8,9)	-0.4	Wunder (1975)
P(8,16)	38.0	Wunder (1975)
-Aves -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)	4.95	Herreid (1967)
P(8,5)	-0.536	Herreid (1967)
P(8,6)	8.59	McNab (1970)
P(8,7)	0.17	McNab (1970)
P(8,8)		
P(8,9)		
P(8,16)	42.0	McNab (1970)
- Reptilia -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)	22.59	Herreid (1967)
P(8,5)	-0.370	Herreid (1967)
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		

Table 8.6a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Amphibia -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		
- Pices -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		
- Crustacea -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		

Table 8.6a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Insecta -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		
P(8,10)	N/A	Refers to parameters not yet implemented in the model
P(8,11)	N/A	Refers to parameters not yet implemented in the model
P(8,12)	0.01	Arbitrarily assigned
P(8,13)	0.40	Arbitrarily assigned
P(8,14)	0.80	Arbitrarily assigned
P(8,15)	0.30	Nagy, et al. (1974)

Table 8.6b. Parameter values for mule deer diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	70000.0	Anderson (1974)
- Male -		
P(8,17)	17000.0	Anderson (1974)
Agropyron		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.39	Golley (1961)
- Winter -		
P(8,20)	0.14	BLM (1980)
- Spring -		
P(8,20)	0.44	BLM (1980)
- Summer -		
P(8,20)	0.02	BLM (1980)
- Autumn -		
P(8,20)	0.09	BLM (1980)
Artemisia tridentata		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.20	Golley (1961)
- Winter -		
P(8,20)	0.66	BLM (1980)
- Spring -		
P(8,20)	0.48	BLM (1980)
- Summer -		
P(8,20)	0.42	BLM (1980)
- Autumn -		
P(8,20)	0.60	BLM (1980)
Forbs		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.39	Golley (1961)

Table 8.6b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.20	BLM (1980)
- Spring -		
P(8,20)	0.08	BLM (1980)
- Summer -		
P(8,20)	0.56	BLM (1980)
- Autumn-		
P(8,20)	0.31	BLM (1980)

Table 8.6c. Parameter values for jackrabbit diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	1878.0	Stoddart (personal communication)
- Male -		
P(8,17)	2342.0	Stoddart (personal communication)
Agropyron		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.49	Golley (1961)
- Winter -		
P(8,20)	0.2	Hamilton (1939), based on cottontail
- Spring -		
P(8,20)	0.6	Hamilton (1939), based on cottontail
- Summer -		
P(8,20)	0.8	Hamilton (1939), based on cottontail
- Autumn -		
P(8,20)	0.6	Hamilton (1939), based on cottontail
Artemisia tridentata		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.25	Golley (1961)
- Winter -		
P(8,20)	0.8	Hamilton (1939), based on cottontail
- Spring -		
P(8,20)	0.2	Hamilton (1939), based on cottontail
- Summer -		
P(8,20)	0.1	Hamilton (1939), based on cottontail
- Autumn -		
P(8,20)	0.4	Hamilton (1939), based on cottontail
Forbs		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.49	Golley (1961)

Table 8.6c. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.0	Hamilton (1939), based on cottontail
- Spring -		
P(8,20)	0.2	Hamilton (1939), based on cottontail
- Summer -		
P(8,20)	0.1	Hamilton (1939), based on cottontail
- Autumn -		
P(8,20)	0.0	Hamilton (1939), based on cottontail

Table 8.6d. Parameter values for small mammal diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	70	Gordon (1943)
- Male -		
P(8,17)	75	Gordon (1943)
Litter		
P(8,18)	5214.0	Golley (1961), average of seeds and insects
P(8,19)	0.75	Hansen (CSU)
- Winter -		
P(8,20)	1.0	Johnson (1961), see text
- Spring -		
P(8,20)	1.0	Johnson (1961), see text
- Summer -		
P(8,20)	1.0	Johnson (1961), see text
- Autumn -		
P(8,20)	1.0	Johnson (1961), see text

Table 8.6e. Parameter values for coyote diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	22000.0	Van Wormer (1964)
- Male -		
P(8,17)	23000.0	Van Wormer (1964)
Small mammal		
P(8,18)	5050.0	Golley (1961)
P(8,19)	0.65	Golley (1961)
- Winter -		
P(8,20)	0.5	Van Wormer (1964)
- Spring -		
P(8,20)	0.5	Van Wormer (1964)
- Summer -		
P(8,20)	0.5	Van Wormer (1964)
- Autumn -		
P(8,20)	0.4	Van Wormer (1964)
Cottontail		
P(8,18)	5000.0	Golley (1961)
P(8,19)	0.59	Golley (1961)
- Winter -		
P(8,20)	0.8	Van Wormer (1964)
- Spring -		
P(8,20)	0.4	Van Wormer (1964)
- Summer -		
P(8,20)	0.5	Van Wormer (1964)
- Autumn -		
P(8,20)	0.5	Van Wormer (1964)
Mule Deer		
P(8,18)	5000.0	Golley (1961)
P(8,19)	0.50	Golley (1961)

Table 8.6e. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.15	Van Wormer (1964)
- Spring -		
P(8,20)	0.1	Van Wormer (1964)
- Summer -		
P(8,20)	0.0	Van Wormer (1964)
- Autumn -		
P(8,20)	0.1	Van Wormer (1964)

Table 8.6f. Parameter values for cow diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	380000.0	BLM (1980)
- Male -		
P(8,17)	460000.0	BLM (1980)
Agropyron		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.43	Golley (1961)
- Winter -		
P(8,20)	0.86	BLM (1980)
- Spring -		
P(8,20)	0.9	BLM (1980)
- Summer -		
P(8,20)	0.9	BLM (1980)
- Autumn -		
P(8,20)	0.86	BLM (1980)
Artemisia tridentata		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.10	Golley (1961)
- Winter -		
P(8,20)	0.14	BLM (1980)
- Spring -		
P(8,20)	0.07	BLM (1980)
- Summer -		
P(8,20)	0.07	BLM (1980)
- Autumn -		
P(8,20)	0.14	BLM (1980)
Forbs		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.43	Golley (1961)

Table 8.6f. (continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.0	BLM (1980)
- Spring -		
P(8,20)	0.03	BLM (1980)
- Summer -		
P(8,20)	0.03	BLM (1980)
- Autumn -		
P(8,20)	0.0	BLM (1980)

Table 8.6g. Parameter values for bighorn diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	287000.0	BLM (1980)
- Male -		
P(8,17)	419400.0	BLM (1980)
Agropyron		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.39	Golley (1961), same as mule deer
- Winter -		
P(8,20)	0.23	BLM (1980)
- Spring -		
P(8,20)	0.94	BLM (1980)
- Summer -		
P(8,20)	0.89	BLM (1980)
- Autumn -		
P(8,20)	0.84	BLM (1980)
Artemisia tridentata		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.20	Golley (1961), same as mule deer
- Winter -		
P(8,20)	0.76	BLM (1980)
- Spring -		
P(8,20)	0.03	BLM (1980)
- Summer -		
P(8,20)	0.05	BLM (1980)
- Autumn -		
P(8,20)	0.07	BLM (1980)
Forbs		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.39	Golley (1961), same as mule deer

Table 8.6g. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.01	BLM (1980)
- Spring -		
P(8,20)	0.03	BLM (1980)
- Summer -		
P(8,20)	0.06	BLM (1980)
- Autumn -		
P(8,20)	0.09	BLM (1980)

Table 8.7a. Parameter values for mule deer population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	145.0	Rue (1978)
P(9,2)	175.0	Rue (1978)
P(9,3)	1.0	BLM (1980), maximum possible
P(9,4)	1.7	BLM (1980)
- Juvenile -		
P(9,5)	365.0	Arbitrarily assigned
P(9,14)	0.50	Robinette (1955)
- Winter -		
P(9,6)	0.0025	Robinette (1955)
- Spring -		
P(9,6)	0.0020	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0015	Robinette (1955)
- Immature -		
P(9,5)	1100.0	Arbitrarily assigned
P(9,14)	0.35	Robinette (1955)
- Winter -		
P(9,6)	0.0015	Robinette (1955)
- Spring -		
P(9,6)	0.0010	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0005	Robinette (1955)

Table 8.7a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	2900.0	Robinette (1955)
P(9,14)	0.15	Robinette (1955)
- Winter -		
P(9,6)	0.0020	Robinette (1955)
- Spring -		
P(9,6)	0.0020	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0010	Robinette (1955)
P(9,7)	1.0	Arbitrarily assigned
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.4	BLM (1980), adjusted
P(9,10)	0.3	BLM (1980), adjusted
P(9,11)	0.45	BLM (1980), adjusted
P(9,12)	0.5	BLM (1980), adjusted
P(9,13)	1.0	BLM (1980), adjusted
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

Table 8.7b. Parameter values for jackrabbit population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	60.0	BLM (1980)
P(9,2)	270.0	Morris (1965), BLM (1980)
P(9,3)	1.0	Morris (1965), based on cottontail
P(9,4)	6.0	Morris (1965), based on cottontail
- Juvenile -		
P(9,5)	120.0	Hamilton (1939), based on cottontail
P(9,14)	0.45	Arbitrarily assigned
- Winter -		
P(9,6)	0.0025	Arbitrarily assigned
- Spring -		
P(9,6)	0.0025	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned
- Immature -		
P(9,5)	300.0	Hamilton (1939), based on cottontail
P(9,14)	0.30	Arbitrarily assigned
- Winter -		
P(9,6)	0.0020	Arbitrarily assigned
- Spring -		
P(9,6)	0.0020	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned

Table 8.7b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	1460.0	Hamilton (1939), based on cottontail
P(9,14)	0.25	Arbitrarily assigned
- Winter -		
P(9,6)	0.0015	Arbitrarily assigned
- Spring -		
P(9,6)	0.0015	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned
P(9,7)	0.5	Arbitrarily assigned
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.1	BLM (1980), adjusted
P(9,10)	0.25	BLM (1980), adjusted
P(9,11)	0.45	BLM (1980), adjusted
P(9,12)	0.5	BLM (1980), adjusted
P(9,13)	1.0	BLM (1980), adjusted
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

Table 8.7c. Parameter values for small mammal population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	120.0	Gordon (1943)
P(9,2)	250.0	Gordon (1943)
P(9,3)	1.0	Gordon (1943)
P(9,4)	6.0	Gordon (1943)
- Juvenile -		This cohort not simulated
P(9,5)	N/A	
P(9,14)	N/A	
- Winter -		
P(9,6)	N/A	
- Spring -		
P(9,6)	N/A	
- Summer -		
P(9,6)	N/A	
- Autumn -		
P(9,6)	N/A	
- Immature -		
P(9,5)	290.0	Arbitrarily assigned
P(9,14)	0.60	Arbitrarily assigned
- Winter -		
P(9,6)	0.0030	Arbitrarily assigned
- Spring -		
P(9,6)	0.0010	Arbitrarily assigned
- Summer -		
P(9,6)	0.0010	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0010	Arbitrarily assigned

Table 8.7c. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	1100.0	Arbitrarily assigned
P(9,14)	0.40	Arbitrarily assigned
- Winter -		
P(9,6)	0.0020	Arbitrarily assigned
- Spring -		
P(9,6)	0.0005	Arbitrarily assigned
- Summer -		
P(9,6)	0.0010	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0010	Arbitrarily assigned
P(9,7)	0.3	Arbitrarily assigned
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.25	BLM (1980), adjusted
P(9,10)	0.1	BLM (1980), adjusted
P(9,11)	0.35	BLM (1980), adjusted
P(9,12)	0.5	BLM (1980), adjusted
P(9,13)	1.0	BLM (1980), adjusted
P(9,15)	340.0	Arbitrarily assigned
P(9,16)	100.0	Arbitrarily assigned

Table 8.7d. Parameter values for coyote population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	120.0	Van Wormer (1964)
P(9,2)	180.0	Van Wormer (1964)
P(9,3)	1.0	Van Wormer (1964)
P(9,4)	10.0	Van Wormer (1964)
- Juvenile -		This cohort not simulated
P(9,5)	N/A	
P(9,14)	N/A	
- Winter -		
P(9,6)	N/A	
- Spring -		
P(9,6)	N/A	
- Summer -		
P(9,6)	N/A	
- Autumn -		
P(9,6)	N/A	
- Immature -		
P(9,5)	270.0	Arbitrarily assigned
P(9,14)	0.95	Arbitrarily assigned
- Winter -		
P(9,6)	0.0015	Arbitrarily assigned
- Spring -		
P(9,6)	0.0010	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0010	Arbitrarily assigned

Table 8.7d. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	1500.0	Arbitrarily assigned
P(9,14)	0.05	Arbitrarily assigned
- Winter -		
P(9,6)	0.0010	Arbitrarily assigned
- Spring -		
P(9,6)	0.0020	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned
P(9,7)	10.0	Arbitrarily assigned
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.2	Arbitrarily assigned
P(9,10)	0.3	Arbitrarily assigned
P(9,11)	0.3	Arbitrarily assigned
P(9,12)	0.5	Arbitrarily assigned
P(9,13)	1.0	Arbitrarily assigned
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

Table 8.7e. Parameter values for cow population. Except, BLM data, parameters based on mule deer.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	100.0	BLM (1980)
P(9,2)	160.0	BLM (1980)
P(9,3)	1.0	Maximum possible
P(9,4)	2.0	Robinette (1955), maximum possible
- Juvenile -		
P(9,5)	400.0	Arbitrarily assigned
P(9,14)	0.7	Robinette (1955)
- Winter -		
P(9,6)	0.0005	Robinette (1955)
- Spring -		
P(9,6)	0.0005	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0005	Robinette (1955)
- Immature -		
P(9,5)	1000.0	Arbitrarily assigned
P(9,14)	0.2	Robinette (1955)
- Winter -		
P(9,6)	0.0005	Robinette (1955)
- Spring -		
P(9,6)	0.0005	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0005	Robinette (1955)

Table 8.7e. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	3600.0	Robinette (1955)
P(9,14)	0.1	Robinette (1955)
- Winter -		
P(9,6)	0.0005	Robinette (1955)
- Spring -		
P(9,6)	0.0005	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0005	Robinette (1955)
P(9,7)	1.0	BLM (1980), adjusted
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.4	BLM (1980)
P(9,10)	0.25	BLM (1980)
P(9,11)	0.2	BLM (1980)
P(9,12)	0.5	BLM (1980)
P(9,13)	1.0	BLM (1980)
P(9,15)	400.0	By definition of no hibernation
P(9,16)	0.0	By definition of no hibernation

Table 8.7f. Parameter values for bighorn population. Except for BLM data, parameters based on mule deer.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	120.0	BLM (1980)
P(9,2)	166.0	BLM (1980)
P(9,3)	1.0	Robinette (1955)
P(9,4)	1.5	Robinette (1955)
- Juvenile -		
P(9,5)	365.0	Arbitrarily assigned
P(9,14)	0.50	Robinette (1955)
- Winter -		
P(9,6)	0.0025	Robinette (1955)
- Spring -		
P(9,6)	0.0020	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0015	Robinette (1955)
- Immature -		
P(9,5)	1100.0	Arbitrarily assigned
P(9,14)	0.35	Robinette (1955)
- Winter -		
P(9,6)	0.0015	Robinette (1955)
- Spring -		
P(9,6)	0.0010	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0005	Robinette (1955)

Table 8.7f. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	2900.0	Robinette (1955)
P(9,14)	0.15	Robinette (1955)
- Winter -		
P(9,6)	0.0020	Robinette (1955)
- Spring -		
P(9,6)	0.0020	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0010	Robinette (1955)
P(9,7)	1.0	Arbitrarily assigned
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.4	BLM (1980), adjusted
P(9,10)	0.3	BLM (1980), adjusted
P(9,11)	0.15	BLM (1980), adjusted
P(9,12)	0.5	BLM (1980), adjusted
P(9,13)	1.0	BLM (1980), adjusted
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

Table 8.8 Soil descriptions for pastures in Garat.

Pasture 1

Soil - Dacker SiL fine-loamy, mixed mesic xerollic durargids

Range Site - loamy 10-13" P.Z. ARTRW/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 8"	Loam	20%	5% fine gravels	2 m pl → 2m sbk
B2t	8-23"	Gravelly clay loam	35%	15% gravels	1 fpr - 2m,f sbk
C1casi	23-50"	Gravelly silty loam	25%	50% durinodes	Massive
C2casim	50-60"	Indurated duripan		-	Massive

Organic Matter - >0.6 organic carbon ∿ 1.0% organic matter (1.3% organic matter)

Surface Rock - 5 to 10% fine alluvial gravels

Depth to Restrictive Layer - 30" duripan

Permeability - moderately slow

Runoff - medium

AWC - 4.56" or medium

Slope - Modal 3% slope

Soil Erosion Equation

F - soil factor 65

R - cover

S - gradient 3% or $(5/10)^{1.35} = (0.20)$

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 1

Soil - Bedstead STX-SiCL clayey-skeletal, montic, mesic abruptic xerollic durargids

Range Site - shallow-claypan 12-16" P.Z. ARAR8/AGSP/FEID

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0-12"	Silty loam	21%	0%	2 Co pl → 2m sbk
B2t	12-60"	Silty clay loam	30%	<5%	2 fpr - 3 f sbk

Organic Matter - 1.1%

Surface Rock - 20% stones, 20% cobbles, 5% gravels

Depth to Restrictive Layer - 5" claypan (abrupt texture change) 25" to duripan

Permeability - slow to very slow

Runoff - moderately rapid

Infiltration - slower than loamy 10-13" P.Z. ARTRW/AGSP soils

AWC - 2.58 low-moderate the break is at 2.5

Slope - Modal 5% slope

Soil Erosion Equation

F - soil factor 79

R - cover

S - gradient 5% (0.39)

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 2

Soil - Dacker SiL fine-loamy, mixed, mesic xerollic durargids
Range Site - loamy 10-13" P.Z. ARTRW/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 6"	Loam	21%	5% gravels 2% cobbles and stones	2 Co pl → 2 sbk
B2t	6-21"	Clay loam	30%	10% gravels	3mf sbk
C1casi	21-61"	Very gravelly silty loam		45% gravels and durinodes	Massive

Organic Matter - ∿1.3%
Surface Rock - 15% gravels
Depth to Restrictive Layer - 30" duripan
Permeability - moderately slow
Runoff - medium
AWC - medium
Slope - Modal 3% slope

Soil Erosion Equation

F - soil factor 65
R - cover
S - gradient 3% (0.20)
L - slope length
P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 2

Soil - Bedstead STX-SiCL clayey-skeletal, montic, mesic abruptic xerollic durargids

Range Site - shallow-claypan 12-16" P.Z. ARAR8/AGSP/FEID

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 7"	Silty loam	23%	10% fine gravels	1 fpl → 2m,f sbk
B2t	7-25"	Silty clay loam	32%	10% fine gravels	1 Co pr
C1casi	25-30"	Fine silty loam	25%	45% fine gravels and durinodes	Massive
C2casim	30-52"	Indurated duripan		-	Massive
Basalt					

Organic Matter - 1.1%

Surface Rock - 20% stones, 20% cobbles, 5% gravels

Depth to Restrictive Layer - 5" claypan (abrupt texture change) 25" to duripan

Permeability - slow to very slow

Runoff - moderately rapid

Infiltration - slower than loamy 10-13" P.Z. ARTRW/AGSP soils

AWC - 2.58 low-moderate, the break is at 2.5

Slope - Modal 5% slope

Soil Erosion Equation

F - soil factor 79

R - cover

S - gradient 5% (0.39)

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 4

Soil - Dacker SiL fine-loamy, mixed, mesic xerollic durargids
Range Site - loamy 10-13" P.Z. ARTRW/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Extremely stony silty clay loam	32%	10% gravels 5% cobbles 5% stones	3 Co pl
B2t	5-25"	Extremely stony silty clay	45%	5% gravels 15% cobbles 35% stones	3 mf abk → sbk
C1casim	25-26"	-		-	Massive
R	26" +	-		-	-

Organic Matter - ∿1.3%
Surface Rock - 5% fine alluvial gravels
Depth to Restrictive Layer - 30" duripan
Permeability - moderately slow
Runoff - slow
AWC - medium
Slope - Modal 3% slope

Soil Erosion Equation

F - soil factor 65
R - cover
S - gradient 3% (0.20)
L - slope length
P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 4

Soil - Bedstead STC-SiCL clayey-skeletal, montic, mesic abruptic xerollic durargids

Range Site - shallow-claypan 12-16" P.Z. ARAR8/AGSP/FEID

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Silty loam	22%	10% fine gravels	1 fpl → 2m,f sbk
B2t	5-20"	Silty clay loam	35%	5% fine gravels	3 mf sbk
C1casi	20-27"	Silty loam	20%	15% fine gravels and durinodes	Massive
C2casim	27-28"	-		-	Massive
C3	28-65"	Sands and gravels		65% gravels	Massive

Organic Matter - 1.1%

Surface Rock - 20% stones, 20% cobbles, 5% gravels

Depth to Restrictive Layer - 5" claypan (abrupt texture change) 25% to duripan

Permeability - slow to very slow

Runoff - moderately rapid

Infiltration - slower than loamy 10-13" P.Z. ARTRW/AGSP soils

AWC - 2.58 low moderate, the break is at 2.5

Slope - Modal 5% slope

Soil Erosion Equation

F - soil factor 79

R - cover

S - gradient 5% (0.39)

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 5

Soil - Dacker SiL fine-loamy, mixed, mesic xerollic durargids
Range Site - loamy 10-13" P.Z. ARTRW/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Extremely stony silty clay loam	32%	10% gravels 5% cobbles 5% stones	3 Co pl
B2t	5-25"	Extremely stony silty clay	45%	5% gravels 15% cobbles 35% stones	3 mf abk → sbk
C1casim	25-26"	-		-	Massive
R	26" +	-		-	-

Organic Matter - 1.3%
Surface Rock - 7% fine alluvial gravels
Depth to Restrictive Layer - 30" duripan
Permeability - moderately slow
AWC - 4.36" medium
Slope - Modal 3% slope

Soil Erosion Equation

F - soil factor 65
R - cover
S - gradient 3% (0.20)
L - slope length
P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 5

Soil - Bedstead STX-SiCL clayey-skeletal, montic, mesic abruptic xerollic durargids

Range Site - shallow-claypan 12-16" P.Z. ARAR8/AGSP/FEID

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 7"	Silty loam	23%	10% fine gravels	1 fpl → 2m,f sbk
B2t	7-25"	Silty clay loam	30%	10% fine gravels	1 Co pr
C1casi	25-30"	Fine sandy loam	25%	35% fine gravels and duripans	Massive
C2casim	30-52"	-		-	Massive
Basalt					

Organic Matter - 1.1%

Surface Rock - 20% stones, 20% cobbles, 5% gravels

Depth to restrictive Layer - 5" claypan (abrupt texture change) 25" to duripan

Permeability - slow to very slow

Runoff - moderately rapid

Infiltration - slower than loamy 10-13" P.Z. ARTRW/AGSP soils

AWC - 2.58 low moderate, the break is at 2.5

Slope - Modal 5% slope

Soil Erosion Equation

F - soil factor 79

R - cover

S - gradient 5% (0.39)

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 6

Soil - Arbridge SL fine-loamy, mixed, mesic xerollic durargids

Range Site - loamy 10-13" P.Z. ARTRW/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Extremely stony silty clay loam	32%	10% gravels 5% cobbles 5% stones	3 Co pl
B2t	5-25"	Extremely stony silty clay	45%	5% gravels 15% cobbles 35% stones	3 mf abk → sbk
C1casim	25-26"	-		-	Massive
R	26" +	-		-	-

Organic Matter - ∿1.3%

Surface Rock - 7% fine alluvial gravels

Depth to Restrictive Layer - 27" duripan

Permeability - moderately slow

Runoff - medium

AWC - medium

Slope - Modal 3% slope

Soil Erosion Equation

F - soil factor 65

R - cover

S - gradient 3% (0.20)

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture 7

Soil - Nevador fine-loamy, mixed, mesic durixerollic haplargids
Range Site - loamy 10-13" P.Z. ARTRW/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Silty loam	23%	10% fine gravels	1 fpl → 2m,f sbk
B2t	5-25"	Silty clay loam	32%	10% fine gravels	1 Co pr
C1casi	25-30"	Fine sandy loam	26%	45% fine gravels and durinodes	Massive
C2casim	30-52"	Indurated duripan	-		Massive
Basalt					

Organic Matter - 1.3%
Surface Rock - 15% fine alluvial gravels
Depth to Restrictive Layer - 50" duripan
Permeability - slow
Runoff - medium
AWC - high
Slope - Modal 7% slope

Soil Erosion Equation

F - soil factor 75
R - cover
S - gradient 7% (0.62)
L - slope length
P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture Miscellaneous

Soil - Lankbush SiL fine-loamy, mixed, mesic xerollic haplargids

Range Site - loamy bottom 12-16" P.Z. ARTRT/POA/CAREX

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Extremely stony silty clay loam	32%	10% gravels 5% cobbles 5% stones	3 Co pl
B2t	5-25"	Extremely stony silty clay	45%	5% gravels 15% cobbles 35% stones	3 mf abk → sbk
C1casim	25-26"	-		-	Massive
R	26" +	-		-	-

Organic Matter - 1.8%

Surface Rock - 0

Depth to Restrictive Layer - none

Permeability - moderately slow

Runoff - slow

Infiltration - higher than loamy 10-13" P.Z. ARTRW/AGSP soils

AWC - 8.4 very high

Slope - Modal 1% slope

Soil Erosion Equation

F - soil factor 55

R - cover

S - gradient 1% (0.04)

L - slope length

P - ppt 0.25 inches/event

Table 8.8 (continued)

Pasture Miscellaneous

Soil - Pedoli-like fine loamy, mixed, frigid xerollic hapargids

Range Site - loamy upland 12-16" P.Z. ARTRT/AGSP

Horizon	Depth	Texture	% Clay	% Rock Fragments	Structure
A1	0- 5"	Silty loam	23%	12% gravel, trace cobbles	1 fpl → 2m,f sbk
B2t	5-25"	Silty clay loam	35%	10% fine gravels	1 Co pr
C1casi	25-30"	Silty loam	25%	35% fine gravels and durinodes	Massive
C2casim	30-52"	Indurated duripan	-		Massive
Basalt					

Organic Matter - 1.6%

Surface Rock - 5% gravels, 2% cobbles and stones

Depth to Restrictive Layer - none

Permeability - moderately slow

Runoff - medium

Infiltration - higher than loamy 10-13" P.Z. ARTRW/AGSP but lower than loamy bottoms

AWC - 5.83 high

Slope - Modal 5% slope

Soil Erosion Equation

F - soil factor 62

R - cover

S - gradient 5% (0.39)

L - slope length

P - ppt 0.25 inches/event

APPENDIX II. SAGEGRASS SOFTWARE

APPENDIX II.1 SAGEGRASS USERS MANUAL

Section 1. File Management
Source Code
Binary Code
Input Files
Output Files
Analysis Programs

Section 2. Program Execution
Flow of Control
Simulation
Interactive Use

Section 3. Programming Techniques
Documentation
Internal Storage Methodology

II.1.1 File Management

The SAGEGRASS model is a very large PASCAL computer program, requiring considerable computer storage space (PRU), and also communicates with many input and output files.

Source Code. SAGEGRASS was coded using the computer language PASCAL 2.0, as implemented on CYBER 172 under NOS 1.4 at Colorado State University, because of the language's tremendous robustness and versatility. The code resides on several indirect access disc files named "SAGEA" -- "SAGEK" (Appendix II.2-II.12).

Table II.1 SAGEGRASS Code File Management

	File	General Purpose	Number of Routines	Compile Time (CPU sec)
1.	SAGEA	data structure	na	na
2.	SAGEB	utility routines	17	12.44
3.	SAGEC	output routines	32	41.30
4.	SAGED	initialization routines	20	29.52
5.	SAGEE	soil water submodel	10	13.20
6.	SAGEF	soil temperature submodel	7	9.77
7.	SAGEG	flora submodel	26	33.02
8.	SAGEH	fauna submodel	34	36.30
9.	SAGEI	management event routines	10	16.27
10.	SAGEJ	reinitialization routines	16	23.77
11.	SAGEK	main simulation driver	4	13.70
		TOTAL	176	229.29**

** Times are for compilation of entire named blocks and are approximate.

These "divisions of labor" have greatly improved the ease of locating and accessing desired subroutines. The file SAGEA contains the data structure which is shared by the other routines. This data structure essentially defines the types of variables and operations defined over them within the model structure. This approach to structuring the source code is also very compatible with the addition (or deletion) of subroutines or interchange of submodels at a later date.

Binary Code. During compilation, the compiler (a PASCAL program) reads in the SAGE source code and converts it to SAGE binary code. The binary code is essentially computer instructions generated by sequences of "0"'s and "1"'s. Since SAGEGRASS is a large computer program, the time required for compilation is also large (Table II.1).

Therefore, the binary code of the SAGEGRASS model is saved, so that it is not necessary to recompile before each simulation. There are two approaches used in creating the binary code. The first is to attach the data structure

to each source code file (as it is being compiled) and to save a binary code file counterpart of each source code file, except the data structure. These binary code files are generally named "BSAGEB" - "BSAGEJ". BSAGEB - BSAGEI are then copied onto one direct access file, "BSAGE2" which takes up approximately 670 PRUs. The program which compiles submodels is listed in II.13. BSAGEJ becomes "BSAGE1" and is saved as an indirect access file. Thus, the major portion of the model (BSAGE2) can be run with different main drivers (BSAGE1). These additional drivers might include debugging routines or program execution timing routines.

The other approach assumes the file BSAGE2 has been created previously. This approach generates the binary code for an individual routine, locates the old binary code in BSAGE2, and replaces the old code with the new. This approach is used when changes have only been made to one or two subroutines on a file and thus recompilation of the other subroutines on the file are unnecessary. However, there is a significant amount of overhead required, so that it is generally only used on files containing more than 12 subroutines. The program which compiles one subroutine at a time is listed in II.14.

Input Files. SAGE currently communicates with four input files (Appendix II.17-II.20), in addition to the system defined "Input" file which is not used. Each file contains specific types of information which may be required during a simulation run. Each file has a loose, but particular format which is dictated by the subroutine accessing it. Different sources of information may be used for different simulation runs by using different input files.

Table II.2 SAGEGRASS Input File Management

	File	PASCAL Code	Information Type	PRU
1.	INPUTA#	WEATHER	climatic driving records	440
2.	INPUTB#	PARAMTR	parameter values	33
3.	INPUTC#	INITIAL	initial conditions	7.5*
4.	INPUTD#	MANAGE	management events	3
			TOTAL	483.5

\# indicates a sequential numbering system
* Varies linearly with ERUs simulated. Value given is for one ERU.

The size of these files can vary considerably. In this example, INPUTA# contains daily records for 11 years; INPUTB1 contains parameters for 6 soil types, 5 plant species and 5 animal species; INPUTC2 contains initial conditions for 2 ERU's; INPUTD1 contains events for controlled burning, spraying herbicides, grazing by livestock and hunting wildlife.

Setting up the input files is the most error prone step in the entire simulation procedure. The best course of action is to put the desired input file on the computer exactly as it is in the appendix (II.13 - II.15). Then, using a text editor, modifying this file to incorporate the desired changes.

If major changes are to be made such as making a run with no animals, it is best to examine the section of source code which reads the data to discover the appropriate changes.

There are several common data errors. Setting up events and initial conditions will be the main sources of problems. In both cases as well as in defining spatially oriented parameters, special care must be taken that spatial units are defined correctly. Giving an ERU a name not found in the parameter file will mean that no plants or animals can be placed on that ERU. Similarly, when moving cattle between ERUs it is easy to move them to a non-existent ERU. When defining ERUs, note that the only allowed grid squares are defined by R101W to R92W and T2N to T8S. These make up an arbitrary 10 by 10 grid between which there is at present no animal movement except by user defined discrete events (see Section 3, main report).

A common error is to make the 10 letter words used in the input files as names, as information, or as descriptors for legibility, either too long or too short. If too short the program may read data as part of the word, throwing succeeding operations off. If the word is too long, the program will read the first 10 letters, then try to read the rest of the letters as data.

Another problem concerns the data itself. All PASCAL data must be surrounded by blanks or end of line or end of file markers. It can read

1.0 200.7 5

where the number of blank spaces is unlimited, but cannot read a FORTRAN type input file of the same data such as

1020075

In addition, all decimal points in the data must be surrounded by numbers so that

1.0 0.02

are legal but

1. .02

are not. Another common data error is to use a letter O instead of zero.

Other data errors may not cause an overt crash of the simluation but may give rise to bizarre results. Thus, an event defined to occur on day 900 instead of day 90 will never occur in a 365 day run. Plant biomass entered in kilograms per hectare instead of grams per square meter will be off by a factor of 10.

Some errors are checked by the program. Events scheduled for nonexistent ERUs are cancelled by the program and an error message is written. Plants or animal species that do not have parameter sets will be cancelled when they are read in. Plants or animals may not be entered onto ERUs which their parameter set defines as illegal. A few other simple errors are checked for.

Output Files. SAGE currently communicates with fourteen output files, in addition to the system defined "OUTPUT" file. These output files are generated at the user's option and contain results for driving variables, state variables, intermediate variables, and processes from the various submodels. Like the input files, the output files can vary considerably in size. In general, "Ouput" is used for output of debugging variable values. For example, when illegal data of certain types which the program checks for is read in, the program disposes of the illegal data and writes an error message to OUTPUT.

Table II.3 SAGEGRASS Output File Management

NOS Name	PASCAL Code	File Description
1. A	RESULTA	soil water intermediate variables
2. B	RESULTB	soil water variables and flows
3. C	RESULTC	soil temp intermediate variables
4. D	RESULTD	soil temp state variables and flows
5. E	RESULTE	floral intermediate variables
6. F	RESULTF	floral state variables
7. G	RESULTG	floral flows
8. H	RESULTH	floral debugging
9. I	RESULTI	fauna intermediate variables
10. J	RESULTJ	fauna state variables and flows
11. K	RESULTK	fauna habitat analysis (6 ERU limit)
12. L	RESULTL	driving variables
13. M	RESULTM	reinitialization output of state variables
14. N	RESULTN	reinitialization output of events
15.	OUTPUT	computer communications, user error messages

Analysis Programs. Currently, the routines which interpret the output files and generate statistical and graphical summaries exist as four stand-alone programs (II.21-II.24). These programs are treated much the same as the source code for the SAGE simulation model.

In order to make printer plots with these routines, they must be compiled with PASCAL3 which includes simple plotting routines which are line printer compatible. If PASCAL3 is not available, they may be converted to PASCAL by changing all ' to # and all ^ to ' and by turning all external PASCAL3 calls into comments. The routines may then be used to reformat simulation output, giving simple columns of numbers which may be plotted by a package such as VERSATEC, thus unscrambling the simulation output which has species within ERUs within days rather than 1 species on 1 ERU for the whole time period which is what must be plotted.

Table II.4 SAGEGRASS Analysis Programs File Management

File	General Purpose	Number of Routines	Source PRU	Compile CPU Time	Binary PRU
1. Climate Results					
CLISTAT	interprets output statistical routines graphical routines reformats output	8	34	12.928	na
2. Soil Results					
a) ANALA1	interprets output	15	39	12.175	48
b) ANALA2	statistical routines	10	32	10.401	37
c) ANALA3	graphical routines	5	25	6.343	23
3. Flora Results					
INTERP	interprets output statistical routines graphical routines reformats output	10	55	27.316	na
4. Fauna Results					
a) ANALF1	interprets output	16	50	14.926	56
b) ANALF2	statistical routines	11	37	11.864	42
c) ANALF3	graphical routines	6	33	8.929	33

These programs operate very similarly. Each communicates with two input files, in addition to "Input", and four output files, in addition to "Output". Each program operates on only selected output files from a simulation run.

Each program has its own Job Control Language file and input file which defines which operations the program is to perform, and for which variables. The input files are largely user readable. After selecting ERUs and variables to be plotted, statistical analysis and data reformatting may be done at the same time if both are desired. If printer plots are possible and desired, the maximum and minimum values for each variable are located on the statistical results output and entered on the plotting input file. The program is then re-run with only the plotting option selected.

Table 11.5 SAGEGRASS Analysis Input-Output File Management

File	PASCAL Code	Information Type
1. Climate Results		
"input"	PLOTCONTROL	user control selections
M	INCLIMATE	input file
na		arrayed data
STATS#	OUTSTATS	statistical summary
PLOTS#	OUTPLOTS	printer plots
2. Soil Results		
ANALAC#	INFILE1	user control selections
B	INFILE2	input file (soil moisture)
D	INFILE2	input file (soil temperature)
REFORM	OUTFILE	arrayed data
SUMSTAT	STATFILE	statistical summary
PLOTS	PLOTFILE	printer plots
3. Flora Results		
"input"	PLOTCONTROL	user control selections
F	INBIO	input file (flora state variables)
G	INFLOW	input file (flora processes)
na		arrayed data
PSTAT#	OUTSTATS	statistical summary
PPLOT#	OUTPLOTS	printer plots
4. Fauna Results		
a) ANALFC#	INFILE1	user control selections
b) J	INFILE2	input file
c) REFORM	OUTFILE	arrayed data
d) SUMSTAT	STATFILE	statistical summary
e) PLOTS	PLOTFILE	printer plots

# indicates a sequential numbering

The size of the input and output files is extremely variable depending upon the user controls selected. Searching the simulation result files for data to be analyzed and/or plotted is very expensive compared to simulation runs. In addition, very long runs or many species will require a great deal of central processor memory for analysis.

II.1.2. Program Execution

Flow of Control. Program control originates from the main driver. Control is passed sequentially to various program activities in response to user control selections. Figure II.1 (and explanatory charts) illustrates the possible flow of control.

To simplify the figure, an order of traversal of the tree is assumed. The order of binary traversal is Visit-Right-Left. By "visit" is meant "perform indicated activity". In this case, "right" means "progress horizontally" and "left" means to "progress vertically". Direction of control flow arrows override the VRL traversal procedure.

As indicated in Figure II.1, certain program activities are order dependent upon preceding activities.

Simulation. All simulations follow the same general procedure, although specific simulations may vary due to user control selections and the number of files actually being used. An example of the Job Control Language used to execute a simulation is listed in Appendix II.15.

The general simulation procedure follows these basic steps:

1. Purge old result and error files
2. Make input files local to the program
3. Copy parameters and initial conditions to output
4. Create new result files
5. Get binary codes and library routines
6. Run simulation binary code
7. Eliminate empty result files
8. Check job status and file status
9. Send output to printer

All but step 9 are automatic, and this step may be made automatic.

If an error condition exists, the basic automatic recovery steps are:

1. Eliminate empty result files
2. Put end of file marks on existing result files
3. Check job status and file status
4. Check dayfile
5. Create and save error file

The user then must examine the error file at the terminal or by routing a copy to the line printer. PASCAL error messages state where in the source the error occurred and give values for all local variables. The most common error is improperly formatted input data.

Execution time per simulation varies greatly, dependent upon several factors:

1. Duration time of simulation
2. Time steps used for each submodel
3. Initial conditions
   a. number of ecological response units
   b. number of soil layers per ERU
   c. number of herbaceous plant species per ERU
   d. number of woody plant species per ERU
   e. number of fauna species per ERU
   f. number of cohorts per fauna species
4. Output files selected to be printed

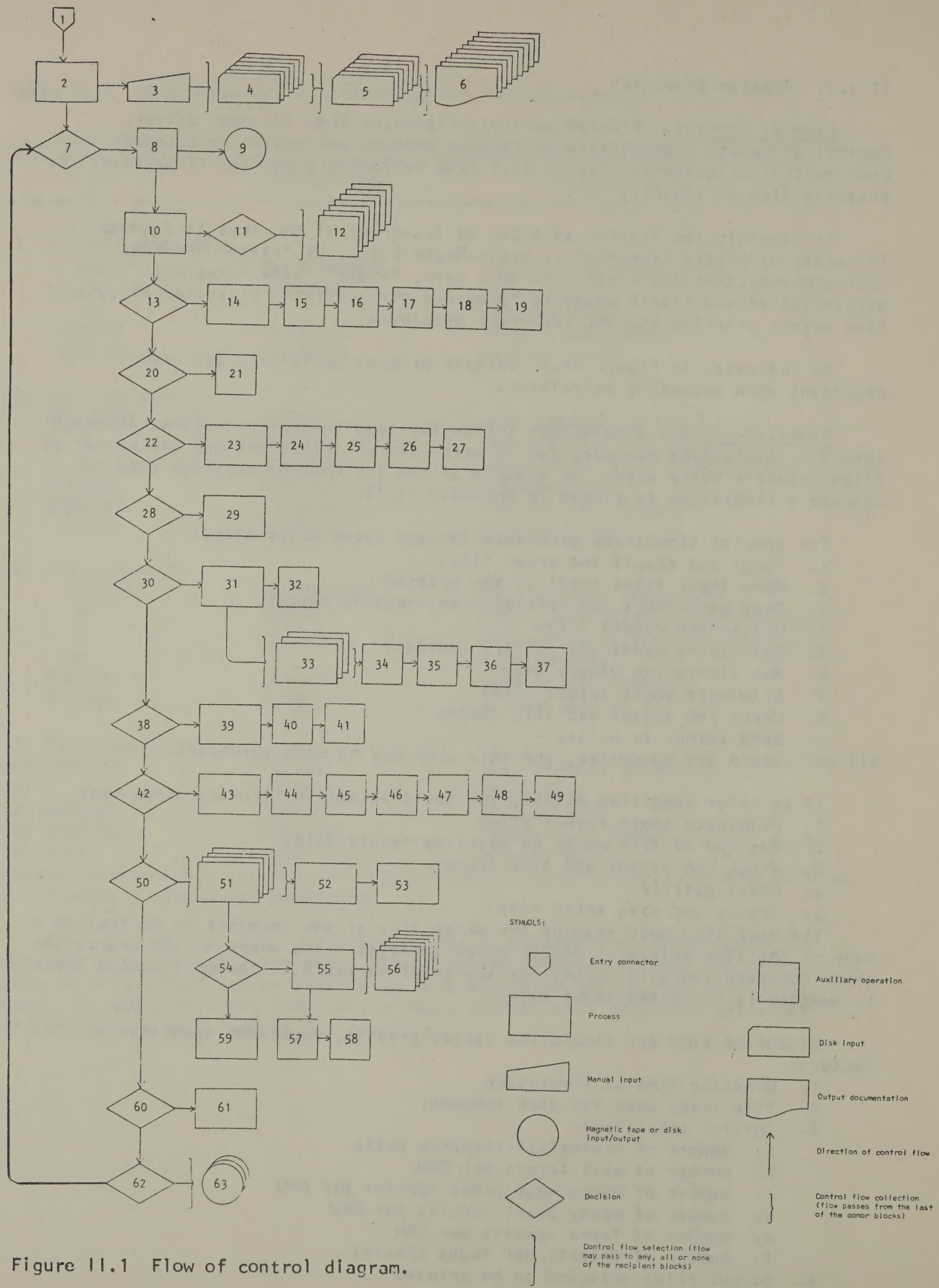


Figure II.1 Flow of control diagram.

Currently, there have not been any execution time analyses performed. However, it is suspected that additional numbers of the initial condition factors do not result in a linear increase in execution times. Due to the use of data structures, it is thought that execution times probably increase logrithmically with additional initial condition factors.

Flow of Control Diagram Key

1 Control entry point to simulation program

2 Main driver routine traces through ERU's and townships
3 User interface for selecting user options
4 Input from disk of parameter values for submodels
5 Input from disk of initial conditions for submodels
6 Input from disk of discrete time event descriptions

7 Simulation decision and time clock
8 Forecast routine updates climatic driving variables
9 Input from magnetic tape of daily weather conditions (disk may be used)

10 Event scheduler for management and development activities
11 Event decision
12 Series of possible events which can be activated

13 Soil moisture submodel activation decision
14 Soil moisture submodel traces through the soil layers
15 Intermediate variable calculations
16 Evaporation process
17 Infiltration process
18 Percolation process
19 Runoff process
20 Transpiration decision
21 Transpiration process

22 Soil temperature submodel activation decision
23 Soil temperature submodel traces through the soil layers
24 Intermediate variable calculations
25 Shortwave and longwave radiation process
26 Vaporization process
27 Conduction process

28 Germination process decision
29 Germination routine traces through all species and germinates if appropriate
30 Flora submodel decision process
31 Flora submodel
32 Phenology process
33 Series of distinct plant type submodels (herbaceous, shrubby, litter)
34 Photosynthesis process
35 Respiration process
36 Translocation process
37 Death of plants parts process

38 Tree submodel activation decision
39 Tree submodel traces through tree species
40 Site index calculation
41 Growth process

42 Fauna submodel activation decision
43 Fauna submodel traces through fauna classes and species
44 Individual metabolism process
45 Individual consumption process
46 Individual assimilation/growth process
47 Population births process
48 Population aging process
49 Population mortality process

50 Submodel update selection
51 Series of abiotic and floral submodel updating routines
52 Flora cover computations
53 Extinction process (after printing)
54 Faunal population movement decision
55 Habitat analysis routines driver
56 Series of habitat characteristic ranking routines
57 Faunal population dispersal process
58 Faunal population colonization process
59 Faunal submodel updating routines

60 Aquatic submodel activation decision (stub only)
61 Aquatic submodel traces through Aqua ERU's within a township (stub only)
62 Output variables and flows selection
63 Output of selected variables and flows

Interactive Use. A kind of interactive usage of the model is possible through the use of the reinitialization procedure. This procedure writes out two files (M and N) that contain the state of the model and of the event queue, respectively. The formats of these files are identical to the standard input files for initial conditions and events. The user can define a length of time for a run, examine the resulting files M and N, decide on event file changes reflecting management decisions, link up M and N as input for a new run, redefine how long to continue the simulation on file M, and rerun the model. There is some overhead involved due to printing the output files and reinitializing the simulation after each interruption.

II.1.3 Programming Techniques

Documentation. The program has been designed to be largely self-documenting. Most variable names have obvious meanings. Additional information on many of the variables can be found in Table 3.2 of the main section of this report, where units and definitions are given and the section of text where the variable is first used or described is cited.

The most important part of the documentation is the data structure itself which defines the types of all variables and shows whether they are parameters, state variables, pointers, etc. Additional local variables are defined within subroutines. These are either given obvious names or they are just temporary storage variables.

All subroutines begin with a brief description of their purpose. There are some additional comments scattered within the code.

The input data is designed to be user readable and is thus largely self-documenting.

Internal Storage Methodology. In a modelling effort of this magnitude, computer storage requirements can easily become limiting. Minimizing storage requirements is thus a major consideration. Taking the plant submodel as our example this involves variant records, dynamic allocation and disposal of flows and many of the intermediate variables, and a special scheme for storing parameters.

Variant records are analogous to a variable dimension array in a FORTRAN subroutine. In this case, the record contains only as many variables as are required by the type of species being modelled. This enables a standard record type to serve for all species without extraneous data storage. A major difference from FORTRAN is that various types (integer, Boolean, real, etc) may all be combined within the same record.

Dynamic allocation is used for flows and some of the intermediate variables. Storage space is created for them at the beginning and destroyed at the end of the timestep for plants. Because each spatial unit is updated in sequence, storage is only required for intermediate variables and flows within a single spatial unit at a time.

Storage for parameters is largely independent of spatial units for plant and animal species. Parameters for all species to be modelled are entered as data. When a plant is created during execution or entered as data, it is linked to the appropriate parameter set by a pointer. Thus the storage requirements for parameters depend only on the number of species over the whole area to be modelled. The same species in different spatial units use the same parameter sets. Exceptions to this are that one record is required for each ERU for each species of plant and animal to define the habitats within which it may occur, and that animal diets must be specified for each ERU.

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